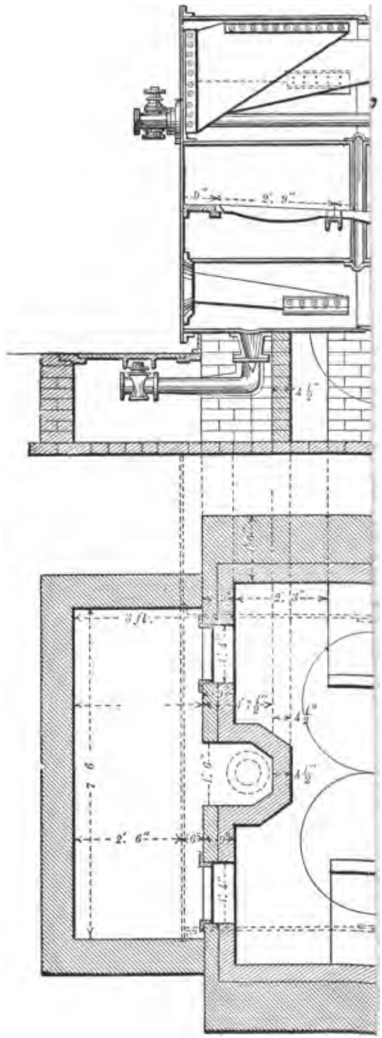
STEAM BOILERS:

THEIR DEFECTS, MANAGEMENT, AND CONSTRUCTION.

LANCASHIRE BOILER.

28ft. by 7ft.



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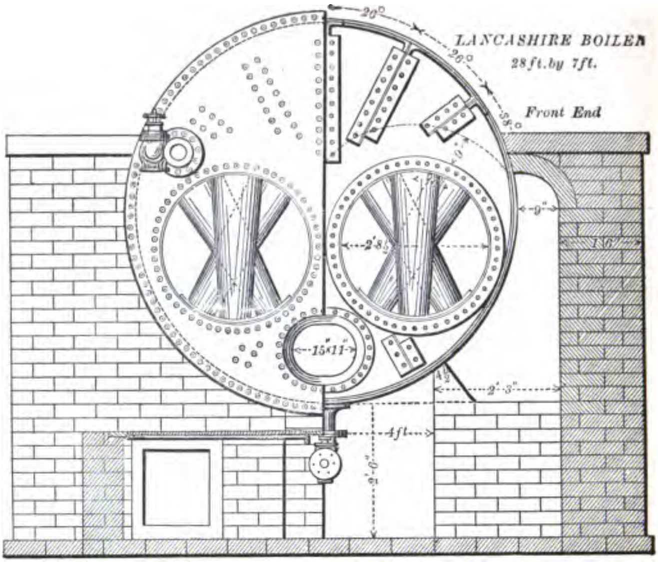

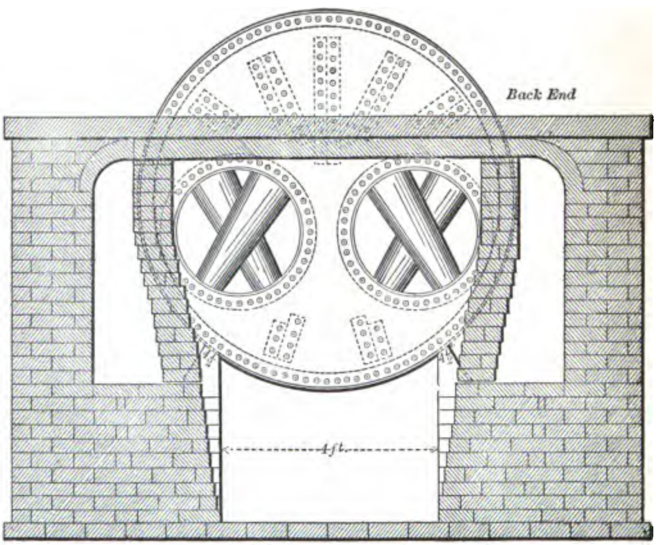

STEAM BOILERS:

THEIR DEFECTS, MANAGEMENT,

AND

CONSTRUCTION.

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BY

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FOURTH EDITION.

With Numerous Illustrations and Tables.

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PREFACE.

The following short treatise on the causes of boiler explosions and their prevention has been written with a view to placing within the reach of boiler-attendants and mill-mechanics such information as may lead them to take a more intelligent interest in the safe working of boilers. The rules and examples have been simplified as much as possible, and as the instructions and suggestions given are based on the collective experience of boiler-designing and inspecting engineers, they may be acted on with confidence. The constants used in compiling the various tables are a safe average of the strength of materials employed in boiler construction, and will be found quite applicable to a majority of the land-boilers in use.

The absurd theories in reference to explosions which are still held by many of those directly interested in the working of boilers, very frequently stand in the way of preventive measures being adopted; and although it may be too much to expect that explosions will ever entirely be prevented, there can be no doubt that until it is clearly understood that boilers burst—as chains and ropes break—when their strength is exceeded, the "stitch-in-time" suggestions will be held so far in contempt.

In conclusion, the writer begs to express the hope that

the publication of this treatise will be instrumental in making clearer some of the points which concern those entrusted with the working of steam-boilers, and that the tables and examples given will enable many to determine for themselves what should be a safe working-pressure for the boilers under their charge.

GLASGOW, *September*, 1887

PREFACE TO THE SECOND EDITION.

THE second issue contains a special section on the Construction and Management of Upright Internally-fired Boilers, together with several additional Tables of Rivetted Joints and Bursting Pressures, &c. A Specification and detailed Drawing of a Lancashire Boiler, for a working pressure of 200 lbs. per square inch, has also been added, and alterations on the subject-matter of the first edition have been made where required.

The Author begs to offer his sincere thanks for the favourable reception accorded to the first edition, and it is his earnest hope that the extensions made in this issue may be of further service to readers of the original work, as well as to those who may now peruse the book for the first time.

GLASGOW, *March*, 1892.

NOTE TO THE FOURTH EDITION.

THE exhaustion of the Third Edition of this work has rendered necessary the issue of a new edition, in presenting which the Publishers desire to record their gratification at the favourable reception that has hitherto attended its publication, which they venture to hope will continue to be accorded it at the hands of Engineers and professional men generally.

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STEAM BOILERS.

INTRODUCTORY.

SINCE the introduction of the Boiler Explosions Act, 1882, 500 boiler explosions have been reported to the Board of Trade,* which, besides damage to property and other loss, have caused 267 deaths, and serious injury to upwards of 500 persons. In addition to the explosions thus recorded, many minor boiler accidents have occurred, which although unaccompanied by any serious results have been the means of causing stoppages of works, with consequent loss to employers and employed.

The investigations made show that the majority of the explosions which have occurred cannot be viewed as accidental, inasmuch as they were due to deterioration and other defects which could have been detected by careful inspection long before their condition became dangerous. The experience gained by the Board of Trade surveyors as to the causes of explosions differs in no respect from that of the Boiler Inspecting Companies, who have for upwards of thirty years been giving such matters their closest attention. The whole history of boiler explosions points to the fact that there have been, and in all probability still are, many boilers at work, which, if examined by competent inspectors, would be found deficient in what experience and rule have proved to be necessary for safety. That a steam boiler

* During the nine years ending 30th June, 1891.

should be of good construction and material, properly mounted and set, is of the first importance; but to insure safety it is necessary that all boilers should be carefully attended when at work, and thoroughly examined by qualified inspectors at least once a year. Under such conditions durability and economy will be secured, and the chances of accident or explosion will be reduced to a minimum.

Incompetency and neglect on the part of attendants, although amongst the causes assigned for boiler explosions, are charged with a very small percentage of those accounted for during the working of the Explosions Act, 1882. This feature of the reports is doubtless very creditable, and shows the absurdity of the statement, still somewhat commonly made, that no explosion could occur unless the fireman allowed his boiler to "run dry." Whilst boiler attendants are thus accredited with satisfactorily performing those duties for which they are generally held responsible, it must be apparent to all who have read the Board of Trade reports that the number of explosions would have been reduced, if the men in charge had been trained to take an interest in the working of their boilers beyond the merely mechanical duties of feeding, firing, and cleaning. It is not to be expected that attendants should be skilled in boiler construction, but there is no reason why they should not be competent to draw attention to defects before they become dangerous, and to form fairly sound conclusions as to how the safety of boilers is affected by deterioration and other evils to which they are subject. That many are thus qualified is well known by the officers of the Boiler Inspecting Companies, and cases occur frequently wherein the experience that careful attendants obtain from daily observation and the periodical inspections at cleaning-times, is of the greatest service in directing the attention of experts to flaws that might otherwise have escaped their observation.

Referring to the training of attendants as a means of obtaining improved supervision of boilers, it has been said that many of them know too much already, as they display great ingenuity in the matter of overloading safety-valves, and otherwise tampering with boilers in such a manner as to increase the dangers attending their use. Actions such as are here referred to, however, can only be attributed to ignorance of the dangers involved, and tend rather to prove that if the ability of which such ingenuity is evidence were properly guided, the number of explosions would be reduced, and the efficiency of boilers increased. The responsibilities of boiler attendants are variously estimated, but they may be reduced to two aspects—the one as indicated in the Board of Trade reports, and the other as understood by a number of steam users. According to the former it would appear that a fireman has done all for which he can be held responsible when he keeps up the required supply of feed-water, and throws into the furnace the amount of fuel necessary to evaporate it into steam. According to the latter, however, the responsibilities of a boiler attendant are of a very high order. Instances of firemen being allowed to give instructions as to repairs and other important matters are by no means uncommon, they being in many steam-using establishments the only individuals who can claim to possess a mechanical knowledge of any kind. The Board of Trade Report, No. 134, refers to a boiler which had been left to the sole management of the attendant, even to the supervision of repairs and alterations, the result being such a reduction of strength that it exploded at the ordinary pressure with disastrous results. The responsibility assigned by the Board of Trade to those in charge of boilers is evidently as far short of what it should be, as that placed upon them by certain steam users is beyond it. The reports clearly show that many of the explosions were the results

of defects so palpable that even the most casual inspection should have detected them; and in these cases, if the attendants had been made to understand that it was part of their duties to look for, and refer all such defects to the judgment of qualified parties, there can be no doubt that many of the explosions would have been prevented. On the other hand, it is quite evident that the apportioning of safe pressures and giving orders as to repairs and alterations, are duties which none but those who are thoroughly conversant with the strength and construction of boilers are competent to perform.

Careful consideration of the evidence adduced from the Board of Trade Reports points to the following conclusions as the best, if not the only, means of preventing boiler explosions:—

First, Steam users in getting new boilers should have detailed specifications prepared by qualified persons, who should also be entrusted with the inspection of the material and workmanship during construction.

Second, Boiler attendants should be made to understand that, in addition to the ordinary stoking duties, it is their business to exercise a general supervision over the boilers and fittings; and all defects observed when boilers are under steam or being cleaned should be carefully noted, and reported for the attention of the inspector.

Third, All boilers should be examined in every part at least once a year by a thoroughly competent inspector, whose business it should be to apportion safe pressures, give instructions as to repairs, and generally to advise the steam user and attendant in all matters relating to the boilers under their charge.

I. EXPLOSIONS CAUSED BY OVERHEATING OF PLATES.

(*a.*) **Shortness of Water** was formerly believed by many, and is still considered by not a few, to be the sole cause of boiler explosions; but although this is by no means the case, it is frequently productive of very serious results. Numerous devices, such as low-water alarums in great variety, and automatic feeds, &c., have been introduced with a view to minimise, if not altogether prevent, boilers being injured in this way; but the best of these are liable to go out of order, and in a number of instances, owing to the confidence placed in their action by attendants, have led to the very results they were designed to obviate. Experience of this kind has occasionally led steam users to conclude—and not without some reason—that such fittings add needlessly to the cost of boilers, and tend to remove the sense of responsibility every fireman should feel.

The most common and at the same time the most reliable indicator of the "water level" is the glass-tube gauge, and when this fitting is of good construction and properly situated, there is no excuse, except under extraordinary circumstances, for the boiler "running dry." Every fireman on taking charge of a boiler should ascertain for himself that the water-gauge is properly situated, and thereby know the actual depth of water over the plates exposed to the direct action of the fire. An approximate idea of this may be obtained even when the boiler is at work; but when it is off, there is no difficulty in arriving at an accurate conclusion. As a general rule, it may be taken that the water-way of a glass gauge should not be less than 3 inches above the furnace crowns of internally-fired boilers, and about the same distance above the highest parts exposed to the fire in the case of externally-fired boilers.

When gauges are set too low—a somewhat common occurrence—there is considerable danger of the feed-supply being neglected, and to prevent this the glass-tubes should be shrouded at the bottom with ferrules of such length, that, when the water is visible in the glass, there will be a depth of 4 inches over the furnace plates.

None of the many sheets of "Instructions to Firemen" omit to caution them that the water gauges should be "tried frequently," in order to ascertain that they are indicating the correct level; but, unfortunately, by many, the method of "trying" is understood to mean simply the occasional opening of the drain tap, and although this practice may tend to keep the passages clear, it is absolutely necessary in all cases, and particularly where the feed-water is bad, that each tap should at intervals be tested independently. The best way of testing the gauge, is to shut the top tap, and by opening the bottom and drain taps, allow the water to blow through freely until the water-way is quite clear; the bottom tap should then be closed, and the top tap opened and blown through in the same manner. By such means the gauge may be relied on to indicate correctly, and the taps will be kept in movable order—a condition, it may be added, the absence of which many have found to be a serious inconvenience on the occasion of a glass-tube breaking. In the majority of works the amount of water that is daily evaporated by each boiler varies little, as a rule, and firemen are accordingly very apt to drop into a routine of duties which will suit the regular conditions, forgetful that boilers sometimes take an unaccountable fit of priming, or that check-valves and blow-off taps, &c., are liable to get into a leaky condition outside of their knowledge, and thus render an increased supply of feed-water necessary in order to prevent the furnace plates being bared.

One of the most serious explosions referred to in the

Board of Trade Reports was the result of shortness of water. In this case, the water-level of one of the boilers in a group of ten was lowered by leakage (supposed to be through a defective blow-off pipe joint) to such an extent, that the plates over a considerable area became softened by overheating, and, rupturing, caused a most violent explosion, which so seriously injured two of the adjoining boilers that they also exploded, the result being that four men were killed, eleven injured, and several thousand pounds' worth of property destroyed. Whilst it is thus evident that shortness of water may be productive of most serious results, and that care is necessary under the best circumstances to prevent its occurrence, it is not the only condition that leads to furnace plates being injured by overheating.

(*b.*) **Deposit.**—The general water supply of this country contains more or less solid matter in suspension and solution; the former consisting of mud or other surface impurities, and the latter of limey substances and minerals, through which the water flows. Surface impurities may be removed by filtration or by allowing the water to settle in ponds before it is used, and in a number of places some such practice as this is carried out. Numerous schemes have been devised for removing the solid matter held in solution, but none, so far, have been so successful as to merit anything like general adoption, and, as a rule, boilers are supplied with water from which few, if any, of the impurities have been removed.

On the evaporation of a given quantity of water, the solid matter it previously contained in solution is left, and in course of time falls to the bottom, or adheres to the plates nearest to the point where it was set free by evaporation.

The quantity of solid matter that the water of this country holds in solution varies very considerably, but an average of 30 grains per gallon may be taken as a fair

estimate. A boiler evaporating 400 gallons per hour would thus—unless preventive means were employed—collect upwards of 20 lbs. per day of 12 hours, and in a short time would be of little service, if not positively dangerous, as a steam generator.

The effect of deposit on the plates exposed to the heated gases from the furnaces is that, in proportion to its thickness and non-conducting properties, it prevents the heat being taken up readily by the water, and is thereby liable to cause such overheating of the plates as to make them unfit to sustain the pressure.

Apart from such serious results as are here indicated, the presence of deposit on the plates is almost certain to cause local straining more or less severe, the result being that frequent repairs become necessary, and the durability of the boilers is materially affected. The chances of injury are very considerably increased if, in addition to deposit, the feed-water becomes impregnated with greasy matter, such as is frequently found in boilers where the water is heated by being in contact with the exhaust steam of high-pressure engines, or is drawn from the hot-wells of condensing engines. In cases of this kind the greasy matter combines with the deposit, and whilst raising its non-conducting properties, makes it adhere so firmly to the plates as to prevent even a partial removal by blowing off. There are, doubtless, many boilers the feed-waters of which are heated by contact with the exhaust steam, or drawn from engine hot-wells, which have worked in this way for years without apparent injury; but whilst granting this, and even admitting the statement sometimes made that the boilers are kept cleaner by such practice, it cannot be denied that even under the best conditions there is an element of danger present, and that it is necessary to exercise the greatest care. The nature of the feed-water and the quality and quantity of the oil are the

principal considerations; if carbonate of lime, magnesia, or organic impurities are present in the water to any extent, the admission of oil is certain to give trouble, and if the lubricant used in the engine cylinders is any other than pure mineral oil, corrosion of the boiler plates, besides overheating, is certain to occur. The quantity of oil that is used in engine cylinders, and consequently the amount that is carried into the feed-tanks, varies, and may at times be excessive. As an illustration of this, an instance of recent occurrence may be quoted. In this case the water supply was practically free from impurities, and although the exhaust steam had been discharged into the open feed-tank for years, the plates of the boiler, with the exception of a little grooving at the furnace seams and end attachments, were in very good condition, and the boiler generally was sufficiently strong for its work. The quantity of oil used in lubricating the piston and valve of the engine was small, and any damage it might have caused, beyond the grooving referred to above, appeared to have been prevented by the system of washing out which was practised. This fairly satisfactory state of matters came to an end in the following manner:—A new piston had been fitted into the engine cylinder, and as it was rather tight, the engineman used his oil-tin freely, the result being that a much larger quantity of oil than usual was carried into the feed-tank, and from it into the boiler. The engine and boiler had only been at work a few days under these circumstances, when the furnace crown plates collapsed, although the glass gauge—which was in good order—indicated a sufficiency of water. An internal examination having been made, the plates of the shell and flues were found besmeared with oily matter, which on the furnace crowns had, by the action of the heat, been converted into a black scale. The furnace plates, fortunately, were of good material, as they withstood the great

strain to which they had been subjected without rupturing, and thus prevented what with inferior material might have been a serious explosion. Many instances of a similar nature might be referred to, but the foregoing will suffice to show that, even where the general conditions are most favourable, circumstances are liable to arise which will render the practice of heating the feed-water by contact with the exhaust steam dangerous in the extreme.

A great deal of interesting matter might be written regarding the various properties of the deposits and impurities found in boilers; but the important question for steam users and firemen to consider is—How are they to be kept from accumulating? for, whatever their nature, it must be evident to all that any substance which prevents the water from being in direct contact with the plates, must tend to reduce the economical working and durability of boilers, and, as has been explained, may be the cause of serious accident. There is, however, no general remedy or method of treating boilers in regard to the impurities contained in the water by which they are supplied. The judicious use of the blow-off taps when boilers are at work, combined with periodical washing out, are so far the principal means whereby deposits may be prevented from accumulating; and according to the nature of the feed-water, and to the manner in which the boiler is worked, so will these means require to be carried out more or less frequently. It is doubtless the case that much good may be done by introducing suitable solvents, whereby the deposits from the water are prevented from forming into hard masses of incrustation; but there are many patented compounds in the market for this purpose, and the greatest care should be exercised in their selection and use, since instances—like the explosion referred to in No. 39 of the Board of Trade Reports—are occasionally met with where the use of a solvent has actually rendered the

deposits from the water more dangerous than they would otherwise have been. The use of special feed-water heaters, as now made by a number of leading firms, is the most effectual method of preventing the solid matter in the feed-water from being a source of trouble. These heaters collect the matter held in solution and suspension, and in districts where the feed-water is bad they are of the greatest benefit. Filtration of the water by any of the simple appliances for this purpose would also do a great deal towards reducing the impurities found in most boilers; and these, along with all other methods which deal with the difficulty *before* the water goes into the boiler, are well worthy of consideration.

The most suitable times for blowing off will vary according to circumstances, but it will generally be found most effective after a boiler has had an interval of quietness, such as may be obtained in many places during meal hours, &c. At times like these, the lighter ingredients, which are held in suspension when the water is in an active state, sink to the bottom, and are thus readily removed.

All boilers, but particularly those which are set in brickwork, should be allowed to cool down gradually before the water is run off, as otherwise the heat retained in the brickwork induces severe straining through unequal expansion. It also causes the deposit to adhere so firmly to the plates as to render its removal a matter of considerable difficulty.

The explosions referred to in the Board of Trade Reports as being the result of impurities in the feed-water, show that the accumulation of non-conducting matter on the plates of a boiler may become a grave source of danger; but they convey a very imperfect idea of the damage and loss that are annually sustained by the steam-using community from this cause.

II. EXPLOSIONS CAUSED BY DEFECTIVE AND OVER-LOADED SAFETY-VALVES.

The percentage of explosions from these causes is high, and goes to show that what are invariably named "safety"-valves should frequently be considered *danger*-valves. The design and construction of safety-valves are often such as to render the keeping of them in order a matter of great difficulty, and they are sometimes in such positions that the shutting of a tap or steam-valve will cut off their connection with the boilers for which they are intended to act. In addition to these drawbacks, it is notorious that there are no mountings so much abused as safety-valves. They are found loaded and overloaded by all kinds of weights, and frequently inoperative by wedging, corrosion, or neglect. Such conduct betokens either great ignorance or a total disregard of the serious risks incurred, and in any case those who are guilty of it cannot be too strongly condemned, or too quickly dispensed with. **Lever Safety-Valves** are most affected by such treatment, for they are easily overloaded, owing to the multiplying power of the lever, by which a slight addition to the weight may increase the load on the valve to a serious extent. They are usually fitted with close-top lever guards, which have the appearance of being specially designed to facilitate the wedging-down process, and, in addition to the chances of corrosion at spindles and valves, the fulcrum joints are liable to become furred up to such an extent as to make the levers immovable.

Notwithstanding these objections to their use, there are few boilers that are not fitted with one or more lever safety-valves, and as many mechanics and boiler-attendants are not conversant with the rules for determining the weights

and dimensions of these valves, the following examples may be of service:—

Fig. 1 represents an ordinary lever valve loaded by means of one weight fixed at the extremity of the lever.

L = the length of lever in inches from the fulcrum to the point at which the ball or weight is suspended.
F = the length of lever in inches from fulcrum to centre of valve.
G = the length of lever in inches from fulcrum to centre of gravity.
A = area of valve in square inches, = square of diameter × ·7854.
W = weight of ball in lbs.
wl = weight of lever in lbs.
wv = weight of valve in lbs.
P = pressure in lbs. per square inch at which the valve should blow.

The lengths L, F, and G should be taken as accurately as possible, and the weights W, *wl*, and *wv* should be taken separately. The lever should be balanced on a knife-edge to find centre of gravity, and having obtained the diameter of the valve, refer to the table on page 24 for its area.

The formula for determining the pressure at which a valve should begin to blow, is as follows:—

$$P = \frac{W \times L + (wl \times G) + (wv \times F)}{A \times F}$$

And substituting figures for letters, let L = 27 inches, F = $3\frac{1}{4}$ inches, G = 10 inches, A = 8·29 square inches ($3\frac{1}{4}$ inches diameter), W = 56·5 lbs., *wl* = 8·5 lbs., and *wv* = 2 lbs.

Fig. 1

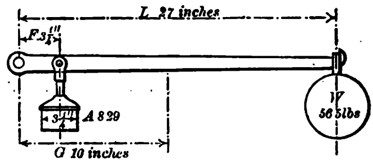


Fig. 3

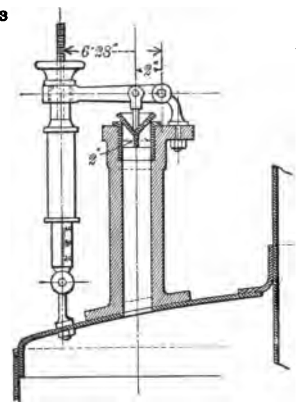


Fig. 4

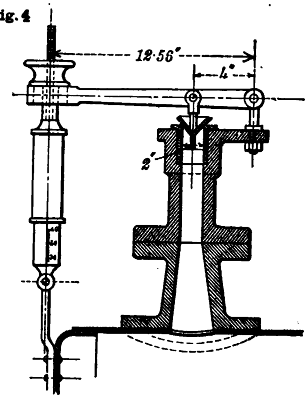


Fig. 2

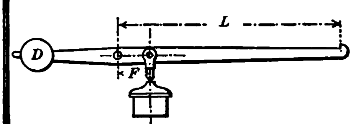
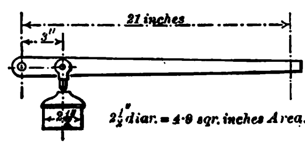


Fig. 5



Then,
$$\begin{aligned} W \times L &= 56{\cdot}5 \times 27 &&= 1525{\cdot}5 \\ wl \times G &= 8{\cdot}5 \times 10 &&= 85{\cdot} \\ wv \times F &= 2{\cdot} \times 3{\cdot}25 &&= 6{\cdot}5 \\ \hline &&& 1617{\cdot} \end{aligned}$$

$$\frac{1617{\cdot}}{\text{Div. by } A \times F = 8{\cdot}29 \times 3{\cdot}25 = 26{\cdot}94} = 60 \text{ lbs. per sq. in.}$$

If the valve is working freely, a pressure of 60 lbs. per square inch would be obtained when L = 27 inches, and the load on safety-valve at any distance less than 27 inches will bear the same proportion to that of 60 lbs. per square inch, as the distance to which the weight has been moved will bear to 27 inches—thus, when L is reduced to $22\frac{1}{2}$ inches, or one-sixth less than 27 inches, the load on valve will be 50 lbs. per square inch, or one-sixth less than 60 lbs., and so on.

When it is required to know at what point the weight or ball should be set to obtain a certain pressure, the formula is

$$L = \frac{A \times P \times F - [(wl \times G) + (wv \times F)]}{W}$$

and taking the pressure obtained (60 lbs.), with the figures given in the first example, the formula is worked out thus—

$$A \times P \times F = 8{\cdot}29 \times 60 \times 3{\cdot}25 = 1616{\cdot}55$$

from which deduct

$$(wl \times G) + (wv \times F) = (8{\cdot}5 \times 10) + (2 \times 3{\cdot}25) = 91{\cdot}5$$

$$\frac{1525{\cdot}05}{\text{Divide the remainder by } W = 56{\cdot}5} = 27 \text{ in.}$$

To find the weight of ball required to give a certain pressure, the formula is the same as in the preceding

example, with the exception that L becomes the divisor—thus,

$$W = \frac{A \times P \times F - [(wl \times G) + (wv \times F)]}{L}$$

When balanced levers are employed, the terms *wl* and *wv* in the preceding formulæ are not taken into account. Fig. 2 represents a balanced lever, the weight D at fulcrum end being equal to the combined weights of lever, valve, and connections; and it follows that W, which is 56·5 lbs. in the foregoing example, must be increased by the amount of the effective weight due to lever, valve, and connections to obtain the same pressure—thus,

$$W = \frac{A \times P \times F}{L} = \frac{8{\cdot}29 \times 60 \times 3{\cdot}25}{27} = 59{\cdot}27 \text{ lbs.}$$

It will be seen from these examples of lever-valves, that the pressure at which they will blow may be seriously affected by even a slight alteration of their dimensions or weights; and it should also be understood that unless the levers, valves, and spindles are *quite free* in their action, it is impossible to arrive at a correct idea of the steam-pressure necessary to lift them.

Lever-valves loaded by "Salter's" spring balances are usually proportioned as illustrated by Fig. 3. The length of the fulcrum (F) is equal to the diameter of the valve, and the total length of the lever (L) is equal to the diameter multiplied by the area (A), the index on the balance being graduated in lbs. By arranging the proportions in this way, a pressure of 1 lb. per square inch on the valve is obtained by each 1 lb. at the end of the lever, and it follows that the number to which the index-finger on the balance points, represents the pressure per square inch on the valve. The formula for calculating the pressure is the same as already explained, the "Salter's" balance being

simply a more convenient arrangement for locomotive and portable boilers, &c., than the ordinary lever and ball. It may, however, be stated that in calculating these valves the effective weight of the lever and valve is not as a rule taken into account.

When safety-valves loaded by "Salter's" balances are of different proportions to those given, it should be ascertained by calculation from the exact dimensions whether 1 lb. at the end of the lever is equivalent to 1 lb. per square inch on the valve; for it frequently happens that the original levers, balances, and valves get separated, with the result that a balance may be found attached to a lever out of all proportion, and that the numbers on the index convey no idea of the lbs. per square inch on the valve. At the same time, although the proportions as in Fig. 3 are very convenient, and are those commonly adopted in good practice, it does not follow that all others are inaccurate; for if it were necessary to have a lever of greater length, it only requires that the relative proportions of F and L be retained to obtain the same results. Thus, with a lever arranged as Fig. 4, where F and L are twice the length, 1 lb. on the index of the balance would also be equal to a pressure of 1 lb. per square inch on the valve. In all cases where the pressure indicated by the balance does not correspond with the load per square inch on the valve, it is of the greatest importance that it should be made to do so; and for this purpose the balance should be tested by suspending therefrom standard weights—say, of 28 or 56 lbs.; if these weights move the pointer to the indices 28 and 56, it will show that the balance has been graduated in pounds, and has been designed for a lever proportioned as in Fig. 3 or Fig. 4. To make the balance correct for different proportions, another index plate must be fitted, having the graduations arranged to suit these. For example, if it were

required to adjust the graduations on the index plate of a spring-balance to suit the proportions given in Fig. 5, the method of procedure would be as follows:—

First ascertain what pressure on the valve would be balanced by a given weight at the end of the lever. The proportions of F and L, Fig. 5, are as 1 is to 7; and it follows that a weight of 7 lbs. at the extremity of the lever would be equal to a total load of $7 \times 7 = 49$ lbs. on the valve, or $\frac{49}{4 \cdot 9} = 10$ lbs. per square inch of valve area. In the same manner, a weight of 14 lbs. on the lever would be equal to a pressure of 20 lbs. per square inch, and so on. The various weights, 7 lbs., 14 lbs., and upwards, as required, should then be suspended from the balance, and the position of the pointer with each weight should be carefully marked on the index plate, after which the spaces between may be equally divided and reckoned up.

The foregoing will serve to illustrate to what a dangerous extent these safety-valves may be overloaded through inaccurate proportions; and this is all the more important when it is considered that the boilers to which safety-valves with spring-balances are applied, usually carry the highest steam-pressures employed. For such reasons they should receive every attention, and the spring-balances should in all cases be fitted with stop-ferrules suitable for the safe loads on the boilers to which they are applied. Care should also be taken to ascertain that these ferrules are of such length as will prevent the spring-balances and safety-valves being rendered inoperative through overscrewing of the spindles.

Dead-weight safety-valves of good construction have many advantages over those of the lever type, and they are rapidly coming into general use.

The rules for ascertaining the proportions of valves and weights are as follows:—

When A and P are known, W is found thus, $A \times P = W$.

A „ W	„	P	„	$\frac{W}{A} = P$.
W „ P	„	A	„	$\frac{W}{P} = A$.

If A = 8·29 sq. ins. and P = 60 lbs., then $W = 8{\cdot}29 \times 60 = 497{\cdot}4$ lbs.

A = 8·29 „ „ W = 497·4 „ „ $P = \frac{497{\cdot}4}{8{\cdot}29} = 60{\cdot}$ „

W = 497·4 lbs. and P = 60 „ „ $A = \frac{497{\cdot}4}{60} = 8{\cdot}29$ sq. in.

It will be seen that a valve having an area of 8·29 square inches requires a weight of 497½ lbs. to obtain a pressure of 60 lbs. per square inch, and that, for every additional 1 lb. per square inch of pressure desired, this weight must be increased by the same number of pounds as there are square inches in the area of the valve. This feature in the dead-weight valve is its great protection against serious overloading, and with those of good type the construction is such that, in the event of extra weights being applied, they cannot fail to attract attention.

AREA OF SAFETY-VALVES.

Safety-valves, besides being accurately loaded and fitted so as to blow at the required pressure, should have a discharging power sufficient to prevent any material increase of pressure under all conditions of working. The term "discharging power" refers to the area of the opening due to the maximum lift of the valve multiplied by its circumference; and unless the opening thus found is proportionate to the working pressure, the amount of fuel consumed, and volume of steam generated in a given time, the pressure in the boiler is liable to rise more or less above that to which the valves are loaded. Under ordinary conditions of work-

ing, the steam generated in a boiler flows freely into the engine cylinder or elsewhere, and with good stoking the quantity required will be regulated so as to prevent any loss through "blowing off." It should be distinctly understood that all steam discharged through the safety-valve is so much heat or power wasted, and it should be the aim of all attendants to economise in this respect as much as possible. Circumstances will occur, however, which render a great discharge of steam through the safety-valves a necessity. An unexpected stoppage of engines when the fires have been made up for full work, will rapidly cause an increase of pressure, and unless the safety-valve outlet is equal to such an emergency, the pressure may accumulate to a dangerous extent. In determining the sizes of safety-valves, the practice was (and is to a certain extent still) to make the area proportionate to the grate surface, or heating surface of the boiler, without taking into account either the pressure to which the boiler is loaded, or that, for a given weight of steam, the volume varies in the inverse ratio of the pressure. The rule most commonly employed requires one-half square inch of safety-valve area for each square foot of grate surface. The sizes of safety-valves thus obtained, whilst giving ample area for boilers, the pressures of which are 60 lbs. per square inch and upwards, would be disproportionate to the requirements of boilers working below 60 lbs., and for the lower pressures the area would be so much under what is required as to make the valves useless in preventing over-pressure.

According to a series of experiments which were conducted by a committee of the Institute of Engineers and Shipbuilders of Scotland it was found that, whilst an opening (square-edged) of 1 square inch discharged 67 lbs. weight of steam per minute at a pressure of 90 lbs. per square inch, it required an opening of 3 square inches to discharge 69 lbs. weight of steam per minute at a pressure of 30 lbs. per square

inch. It will be seen that the area of opening required to discharge 67 lbs. weight of steam at the higher pressure was just one-third of that necessary to discharge 69 lbs. weight of steam at the lower pressure. The same results were obtained throughout the experiments referred to, and, as pointed out in the committee's report, they show that the area required to discharge any given constant weight of steam varies almost inversely as the pressure.

The lift of safety-valves of the ordinary type is very limited, rarely exceeding one-eighth of an inch, and this amount multiplied by the circumference of the valve may be taken as the measure of its discharging power. To obtain the amount of clear opening necessary to discharge all the steam generated in an ordinary land boiler of maximum size, the diameter of a single safety-valve (for low-pressure particularly) would require to be considerable;

Boiler Pressure.	Area of Safety-Valve per Square Foot of Grate Surface.	Boiler Pressure.	Area of Safety-Valve per Square Foot of Grate Surface.
15 lbs.	1·250 sq. in.	70 lbs.	·441 sq. in.
20 „	1·071 „	75 „	·416 „
25 „	·937 „	80 „	·394 „
30 „	·833 „	85 „	·375 „
35 „	·750 „	90 „	·357 „
40 „	·681 „	95 „	·340 „
45 „	·625 „	100 „	·326 „
50 „	·576 „	105 „	·312 „
55 „	·535 „	110 „	·300 „
60 „	·500 „	115 „	·288 „
65 „	·468 „	120 „	·277 „

but as a greater diameter than 4 inches is objectionable, the additional area should be made up by using two or more valves as required. According to the rules at present authorised by the Board of Trade, the area per square foot of fire grate should not be less than that given in the foregoing tables opposite the boiler pressures intended. These tables refer chiefly to the proportions of safety-valves required for marine boilers; and as the amount of water evaporated per square foot of grate surface by these is usually in excess of that in land boilers, the sizes obtained by the rules may be taken as ample for land boilers under ordinary firing.

Specially designed safety-valves are now made, which are guaranteed to have a lift equal to one-fourth of their diameter without any increase of pressure over that to which they are loaded; and as the opening formed by the lift of such valves would be equal to their area, a great discharging power can thus be obtained with valves of small diameter.

Where lever-valves are used, the lever and weight should be so proportioned that when the weight is at the extremity of the lever, the required pressure will be obtained. This precaution reduces the chances of overloading so common when levers are too long, and if irregular weights should be attached, they are more likely to be noticed. The steam faces of safety-valves of good construction are usually from one-sixteenth to one-twelfth of an inch in breadth, but after a time, through repeated grinding, they are frequently found much broader, and great difficulty is experienced in keeping them tight. Valves in this condition are very liable to be seriously overloaded, as, to the unthinking attendant, extra weight is the only remedy that will prevent the steam from escaping, whereas it is more likely to aggravate the cause of the leakage by twisting the valve out of shape.

With valves of fair construction, whether flat-faced or

conical, it is an easy matter to reduce the width of the faces, and this should always be done when they exceed one-eighth of an inch, as, apart from the trouble of keeping the broad surfaces in steam-tight order, such valves cannot be accurately loaded; the latter difficulty will be most apparent after the valve begins to blow, as the increased area which the broad face presents to the steam will keep the valve open until the pressure is reduced considerably below that at which it began to blow, and there is thus more or less waste of steam and danger of additional weights being applied to prevent it.

Escape Pipes.—When rising or vertical escape pipes are attached to safety-valves, they should be fitted with drain pipes, so arranged that the top of the valves and the casings will be perfectly free from even the smallest accumulation of water. Inattention to this precaution has been the cause of many serious accidents; for, in addition to the valve being overloaded in proportion to the weight of water that is above it, there is the danger of the scalding contents of the escape pipe being violently ejected when the valve begins to blow. Rapid corrosion of the casings and valve spindles is also quite common unless the condensed steam is thoroughly drained off, and many instances are known of safety-valves being rendered inoperative during the winter season through the water in escape pipes being frozen. The area of the escape pipe should always be rather over than under that of the valve, and in no case should the pipes be led into chimneys or other invisible corners, since the pipes of themselves, however well arranged, present sufficient difficulty in the way of ascertaining that the valves are in working order.

The Board of Trade Reports show that a considerable number of the explosions which have occurred within the last four years have been partly, or wholly, due to safety-

valves being defective in one or other of the ways indicated, and it is to be hoped that the publication of these reports, with their tales of injury to person and property; will have a salutary effect upon those who have hitherto treated carelessly or ignorantly such important fittings as safety-valves.

TABLE OF DIAMETERS AND AREAS OF CIRCLES FROM 1⅛ INCH TO 6 INCHES.

Dia.	Area.	Dia.	Area.	Dia.	Area.	Dia.	Area.	Dia.	Area.	Dia	A ea.
1⅛	·994	1 15/16	2·948	2¾	5·939	3 9/16	9·967	4⅜	15·033	5 3/16	21·125
1 3/16	1·107	2	3·141	2 13/16	6·212	3⅝	10·320	4 7/16	15·465	5¼	21·647
1¼	1·227	2 1/16	3·341	2⅞	6·491	3 11/16	10·679	4½	15·904	5 5/16	22·166
1 5/16	1·352	2⅛	3·546	2 15/16	6·777	3¾	11·044	4 9/16	16·349	5⅜	22·690
1⅜	1·484	2 3/16	3·758	3	7·068	3 13/16	11·415	4⅝	16·800	5 7/16	23·221
1 7/16	1·622	2¼	3·976	3 1/16	7·366	3⅞	11·793	4 11/16	17·257	5½	23·758
1½	1·767	2 5/16	4·200	3⅛	7·669	3 15/16	12·176	4¾	17·720	5 9/16	24·301
1 9/16	1·917	2⅜	4·430	3 3/16	7·979	4	12·566	4 13/16	18·190	5⅝	24·850
1⅝	2·073	2 7/16	4·666	3¼	8·295	4 1/16	12·962	4⅞	18·665	5 11/16	25·405
1 11/16	2·236	2½	4·908	3 5/16	8·617	4⅛	13·364	4 15/16	19·147	5¾	25·967
1¾	2·405	2 9/16	5·157	3⅜	8·946	4 3/16	13·772	5	19·635	5 13/16	26·534
1 13/16	2·580	2⅝	5·411	3 7/16	9·280	4¼	14·186	5 1/16	20·129	5⅞	27·108
1⅞	2·761	2 11/16	5·672	3½	9·621	4 5/16	14·606	5⅛	20·629	6	28·274

To find the area of a circle, multiply the square of the diameter by ·7854 $A = D^2 \times {·}7854$.

TABLE OF WEIGHT OF CAST-IRON SPHERES.

SOLID CYLINDERS ONE FOOT LONG, AND SQUARE BARS ONE FOOT LONG.

Diameter of Sphere and Cylinder or Side of Square.	Weight of Sphere.	Weight of Solid Cylinder One Foot in Length.	Weight of Square Bar One Foot in Length.	Diameter of Sphere and Cylinder or Side of Square.	Weight of Sphere.	Weight of Solid Cylinder One Foot in Length.	Weight of Square Bar One Foot in Length.
3 ins.	3·7lbs.	22· lbs.	23·1lbs.	7¾ ins.	63·4lbs.	147·4lbs.	187·7lbs.
3¼ ,,	5·8 ,,	30· ,,	38·3 ,,	8 ,,	69·8 ,,	157· ,,	200· ,,
3¾ ,,	7·2 ,,	34·5 ,,	43 9 ,,	8¼ ,,	76·5 ,,	167· ,,	212·6 ,,
4 ,,	8·7 ,,	39·3 ,,	50· ,,	8½ ,,	83·7 ,,	177·1 ,,	225·8 ,,
4¼ ,,	10·4 ,,	44·3 ,,	56·4 ,,	8¾ ,,	91·3 ,,	187·9 ,,	239·3 ,,
4½ ,,	12·4 ,,	49·7 ,,	63·3 ,,	9 ,,	99·4 ,,	198·8 ,,	253·1 ,,
4¾ ,,	14·6 ,,	55·4 ,,	70·5 ,,	9¼ ,,	107·9 ,,	210· ,,	267·4 ,,
5 ,,	17· ,,	61·4 ,,	78·1 ,,	9½ ,,	116·9 ,,	221·5 ,,	282· ,,
5¼ ,,	19·7 ,,	67·6 ,,	86·1 ,,	9¾ ,,	126·3 ,,	233·3 ,,	297· ,,
5½ ,,	22·7 ,,	74·2 ,,	94·5 ,,	10 ,,	136·4 ,,	245·4 ,,	312·5 ,,
5¾ ,,	25·9 ,,	81·1 ,,	103·3 ,,	10¼ ,,	146·7 ,,	257·8 ,,	328·3 ,,
6 ,,	29·5 ,,	88·4 ,,	112·5 ,,	10½ ,,	157·8 ,,	270·6 ,,	344·5 ,,
6¼ ,,	33·3 ,,	95·9 ,,	122· ,,	10¾ ,,	169·3 ,,	283·6 ,,	361·1 ,,
6½ ,,	37·4 ,,	103·7 ,,	132· ,,	11 ,,	181·5 ,,	297· ,,	378·1 ,,
6¾ ,,	41·9 ,,	111·8 ,,	142·4 ,,	11¼ ,,	194· ,,	310·6 ,,	395·5 ,,
7 ,,	46·8 ,,	120·3 ,,	153·1 ,,	11½ ,,	207·3 ,,	324·6 ,,	413·3 ,,
7¼ ,,	51·9 ,,	129· ,,	164·3 ,,	11¾ ,,	221· ,,	338 9 ,,	431·4 ,,
7½ ,,	57·5 ,,	138· ,,	175·8 ,,	12 ,,	235·6 ,,	353·4 ,,	450· ,,

III. EXPLOSIONS CAUSED BY CORROSION.

Of all the evils with which boiler-owners have to contend there are none so insidious or so destructive as that of corrosion. This has been the experience of all who have given the matter attention, and the returns of the Board of Trade also show that corrosion of the plates of boilers is still the chief agent in bringing about disastrous explosions.

Corrosion occurs both internally and externally; and whilst the former is sometimes very difficult to deal with, the latter is so easily prevented that its existence can only be taken as an indication of carelessness on the part of those responsible for the boilers affected.

(*a.*) **Internal corrosion** is sometimes found in the form of general deterioration, the plates below the water-line being reduced in thickness throughout. It occurs also in the form of blotching, the plates being thinned more or less over surfaces of varying area, whilst at other parts they may be unimpaired. Another, and perhaps the commonest form of internal corrosion, is that known as "pitting," which gives the plates attacked very much the appearance of a face that has been ravaged by small-pox. In addition to the various forms of corrosion referred to, boilers are liable to be affected by internal grooving, a defect which, though induced by mechanical action, developes all the more rapidly when the feed-water is of a corrosive nature.

The causes of internal corrosion have engaged attention from a very early period in our steam-using history, and numerous as well as varied have been the theories propounded and remedies suggested. In these days, however, most authorities are agreed that internal corrosion is due to the presence of certain acids in the feed-water; and the manner in which these acids will affect the plates, whether

in the form of general deterioration, blotching, or pitting, depends on the nature of the material and the conditions to which it is exposed.

General deterioration is a very dangerous form of corrosion, for the plates, although seriously affected, are liable—owing to their uniform appearance—to be passed as sound. When corrosion of this kind is suspected, the overlaps of the seams should be carefully examined, as it is there the reduction is most likely to be detected; the plates should also be drilled to ascertain the actual thickness. Boilers supplied with water from certain pits and mines are liable to be affected by corrosion in this form. The waters obtained from moorland districts have also been found at times to have the same effect, and it is worthy of notice that such waters, as a rule, contain very little, if any, solid matter. The absence of sediment doubtless facilitates inspection, but the introduction of small quantities of limey matter with these feed-waters has been found advantageous in protecting the plates from the action of the corrosive acids.

Blotching and pitting are sometimes ascribed to a want of uniformity in the material, by which certain parts are more susceptible to the action of acids than others, it being the general experience that the purest iron offers the least resistance to the inroads of corrosion. The different conditions of temperature, &c., to which the various parts of a boiler are subjected will also account for some of the plates (or it may be parts of the same plate) being more seriously affected than others, and the corrosive agencies in the water have frequeutly been found to concentrate at certain parts, leaving the remainder of the boiler quite free from attack.

The progress of internal corrosion has frequently been arrested by the introduction of a quantity of soda with the feed-water, this having the effect of neutralising the acidity. There are many compounds advertised which are guaranteed

to prevent internal corrosion; but, whilst several have been fairly successful, there are others which contain impurities more or less hurtful; and in any case, as the best of these specifics are mostly composed of soda, it will be found cheaper and more satisfactory to use soda by itself. The quantity required will vary according to circumstances, and can only be determined after careful trial and examination of its effects upon the plates. With certain feed-waters, the introduction of a very small quantity of common soda will cause foaming or priming; and where special antidotes for corrosion are used, the greatest caution should be observed, as these not infrequently contain greasy matter, which is very liable to bring about serious priming as well as other injurious results.

There are instances of internal corrosion upon which all the known remedies have been tried, and have failed to produce any beneficial result. In such cases—as will be evident—a change of feed-water is required; but when this is impracticable, the deterioration due to corrosion can only be prevented from becoming dangerous by vigilant inspection, judicious repair, and timely renewal.

Grooving of plates and angles is induced by expansion and contraction resulting from variations of temperature and pressure. It is very commonly found in Lancashire and Cornish boilers at, or immediately over, the flue attachments to end-plates. The crown-plates of the flue tubes in these boilers being directly acted on by the furnace gases, attain a much higher temperature than the plates along the undersides, and the greater expansion of the crowns thus caused being resisted by the end-plates, leads to arching or bending of the flues in the direction of their length. This action varies with the temperature of the furnaces, and its effects at the end attachments depend to a considerable extent on the manner in which the end-plates are stayed,

either excess or insufficiency of rigidity having a like result, so far as grooving is concerned. Grooving is liable to occur at and about the narrow water spaces of internally fired boilers through inequality of temperature of the furnaces. It is also found round the roots of the angle-irons or flanges by which the end-plates are attached to shells—more especially in unstayed, flat, or bulged ended boilers—owing to the bending movement set up by varying internal pressures. Explosions Nos. 6 and 148 in the Board of Trade Reports illustrate how the grooving, to which such boilers are thus liable, may result in rupture and explosion. Grooving occurs at the lap edges of the circumferential seams of boilers set horizontally, owing to the difference of temperature between the upper and lower parts of shells; it is also found running along the edges of the longitudinal lap joints, especially in small boilers when exposed to high pressures, the majority of the explosions of locomotive boilers reported to the Board of Trade being due to this cause. "Longitudinal" grooving, as this latter form of the defect is termed, is caused by the indirect straining that exists at the lap joints, owing to the tendency of the internal pressure to make the boiler assume a perfectly cylindrical form, and according to the variations of pressure so will grooving at the lap edges develope more or less rapidly; the diameter of a boiler, the thickness of its plates, and the breadth of the laps have also an important bearing in this respect. Under the most favourable conditions, however, experience has proved that small boilers, such as those of locomotives and others exposed to high pressures, must be made perfectly cylindrical to escape this dangerous form of decay, which necessitates butt-jointing or welding at the longitudinal seams.

There is often considerable difficulty in detecting internal grooving, particularly when it takes place in boilers fed with water of a non-corrosive nature. In such cases it

appears more like a fine fracture running along the edges of the laps, and it may reach to a dangerous depth without opening to any extent at the surface. When a defect of this nature is discovered, the plate should be drilled to ascertain its actual depth, and no opportunity should be allowed to pass without having it carefully examined; it should also be remembered that as the section of the plate becomes reduced, the "wear and tear" of the material along the line of fracture will be proportionately increased. With feed-water of a corrosive nature, grooving extends rapidly, owing to the action of the acids on the strained surfaces exposed. Its appearance under such conditions differs considerably from that referred to, and is perhaps more correctly described as "channelling" or "furrowing." In this form the defect is easily detected, as it is commonly found from ⅛ inch to 1 inch in width; careful examination, however, is necessary to determine the depth of the grooving along the lines most affected by the bending stresses, which, as already explained, run close to the edges of the laps and angle-irons, or round the roots of angle-irons and flanges.

Internal grooving is induced by straining, through unequal expansion, or varying pressures; and although improved construction has done much towards minimising this form of deterioration, it is only when good boilers are fairly worked and attended to, that it is found to be of little importance. The difference of expansion which exists more or less between the upper and lower parts of the internal flues and shells of Lancashire boilers, for instance, may be aggravated greatly by the deposits from the feed-water, and the bottom plates of externally fired boilers are frequently found fractured through the rivet holes of the ring seams by the same cause. Forced firing is also certain to increase the inequalities of temperature in all types of boilers, and, indeed, has been known to do so to such an extent as to

induce sudden fracture and explosion. In short, experience has shown that, although all boilers are more or less subject to internal corrosion and grooving, these defects are rarely a source of accident, except in boilers where deposits are allowed to accumulate and immoderate firing is resorted to, as a means of maintaining their evaporative power. Deposit, as has been shown, leads to waste of fuel, and is frequently the means of causing overheating, corrosion, and grooving; it also prevents inspection, which alone can give a sense of security as to the safety of boilers. Corrosion and grooving have too often been hidden under a coating of incrustation until explosion occurred; and were it for no other reason than that of facilitating examination, the necessity of keeping boilers clean cannot be too strongly impressed upon all concerned. The means for effectually preventing the decay of boilers through internal corrosion are in many instances unobtainable, and all that can be done is to watch its progress carefully, and to have repairs executed or boilers replaced as found necessary in the interests of safety.

(*b.*) **External corrosion**, although easily accounted for and prevented, is much more dangerous than internal corrosion, and from statistics it will be found that this form of decay has been the cause of more explosions than any other.

Dampness and leakage are the chief promoters of external corrosion. The former of these may be due to the boilers affected being in close proximity to a stream, or to their structure being such that the brickwork in which they are set is liable to be affected by rain or surface water. The under sides of boilers, particularly where in contact with the bearing walls, are the portions which corrode most rapidly under these influences, and as they cannot be seen unless the brickwork is removed, there is often considerable danger of corrosion going on undetected until the material is seriously impaired. This is particularly the case with

boilers seated on broad mid-feather walls, or with those having external flues which are too confined for inspection.

The setting of a boiler is of the utmost importance, not only in regard to corrosion, but also as a means of economising fuel and preventing the undue "wear and tear" of the plates from other causes. This is a matter which has deservedly received the attention of the best authorities on the subject, and there can be no question as to the wisdom of giving effect to the following rules, which have been laid down for guidance in the setting of boilers:—

(1.) In selecting a site for boilers, care should be taken to ascertain that it will not be exposed to dampness from streams, drains, or surface moisture; but if, owing to the nature of the soil or to any other circumstance, such a situation is impracticable, the boiler setting should be built on a foundation of concrete sufficient to prevent dampness from ascending into the brickwork; precautions should also be taken by draining or otherwise to guard against water from higher levels collecting at and about the foundations.

(2.) The flues should be made large enough to admit of easy access to every part of the external surface of the boiler. They should also be arranged so as to give such a circulation of the gases from the furnaces as will tend to utilise their heat to the greatest extent, and at the same time reduce as much as possible the difference of temperature between the top and the bottom of the boilers.

(3.) The closing-in tiles of side flues should be placed so as to prevent the gases from traversing the plates above the water-line.

(4.) The bearing walls should be coped with suitable fire-clay blocks for the boilers to rest upon; but in cases where these blocks are not used, the upper portions of the bearing-walls should be reduced to a minimum breadth, and

as lime or mortar in contact with the plates causes rapid corrosion, fire-clay only should be used at these parts.

Figs. 6, 7, and 8 are cross-sections of settings for plain cylindrical, Cornish, and multitubular boilers, and they represent respectively the methods most likely to meet the requirements of cleaning and inspection, besides giving the best general results in other respects. It will be observed that the setting of plain cylindrical boilers (Fig. 6) is that commonly known as the "flash flue." The side walls are closed in according to the third rule given above, thus leaving about one-half the surface of the boiler exposed to the furnace gases, which, after traversing this surface, are led direct to the chimney. The external flues of these boilers are sometimes arranged for a "wheel draught," the gases being led along the bottom towards the back end, returning through one of the side flues to the front end, and thereafter by the opposite side-flue to the chimney. This plan, however, except with very short boilers, has few advocates, as any economy of fuel that may be derived from such a distribution of the gases is more than covered by the increased cost of brickwork and cleaning. Externally-fired boilers are sometimes suspended from cross girders, as shown by Figs. 6 and 9, and wherever this method has been adopted, it has been found to act very satisfactorily. The most ordinary way of supporting them, however, is by means of brackets attached at suitable distances along each side of the boiler. The plates to which these brackets are attached are liable to be strained by the movements of the boiler from alternate expansion and contraction, or by the unequal subsidence of the brickwork on which they rest, and many serious cases of fracture, and consequent corrosion, have occurred from these causes. Side brackets should always be soundly rivetted to the plates, as the somewhat too common practice of using bolts for this purpose almost invariably results in

Fig.6

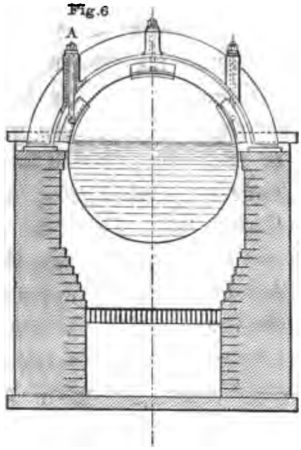


Fig.9

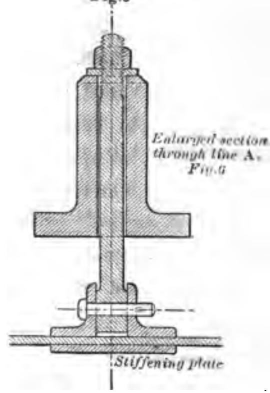


Fig.7

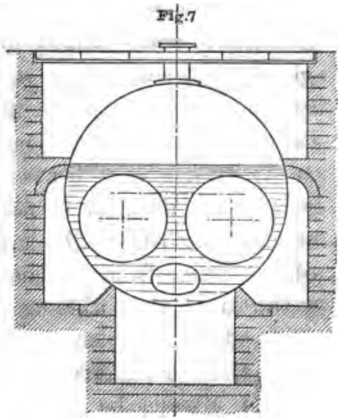


Fig.8

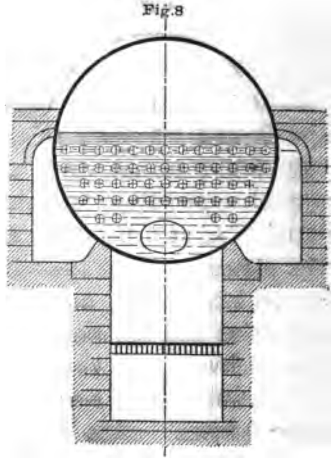


Fig. 10

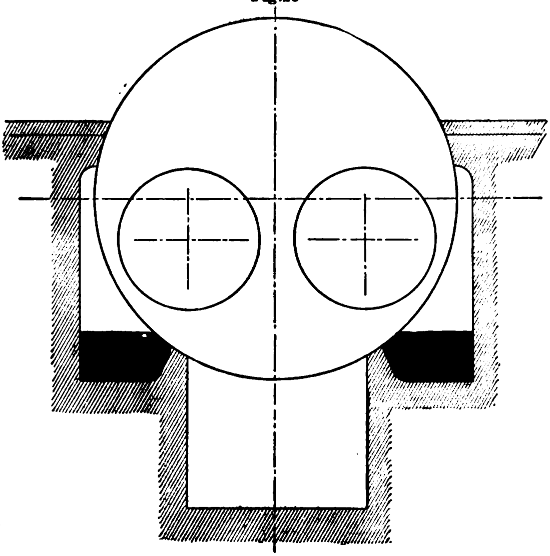
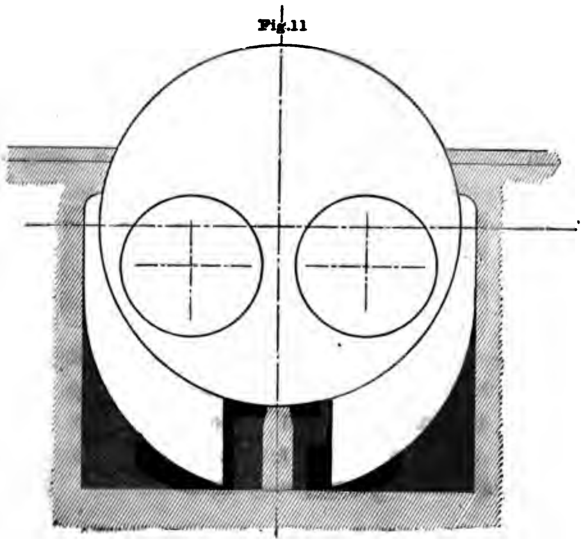


Fig. 11



leakage, and as they are usually covered by brickwork, corrosion of the plates and bolts may go on to a serious extent undetected. Stiffening plates should also be rivetted at water sides, as shown by Fig. 9, in order to strengthen the plates to which the brackets are attached.

The mode of setting Lancashire or Cornish boilers, illustrated in cross-section by Fig. 7, and in detail on *Frontispiece*, although very generally adopted, is not always arranged to the best advantage. In some cases the gases on leaving the internal tubes are led into the side flues, and from thence along the bottom flue to the chimney, and there are many who contend that by such a distribution the heat is more effectively utilised; but, however this may be, there can be no doubt that it tends to increase, rather than decrease, the difference of temperature between the upper and lower parts of the shell, and is thereby liable to cause straining and grooving at the ring seams. The side flues of boilers are sometimes so confined that the cleaning of them out is an operation of the greatest difficulty, and inspection without taking down the brickwork is impossible, the result being that leakage, corrosion, and other defects often escape detection until they become dangerous; moreover, it has been clearly proved that narrow flues are detrimental to economy of fuel. Contracted flues can in most cases be rendered accessible with very little alteration in the building, for although the lateral space may be limited by adjoining walls, the flues can be deepened and enlarged in the manner indicated by Figs 10. and 11.

Broad bearing-walls, like narrow flues, hide defects, and if there be any dampness through leakage or otherwise, it usually lodges about the seatings. Numerous instances might be given wherein boilers quite good in other respects were rendered dangerous owing to corrosion at these parts escaping detection. The greatest

width of bearing-wall, where in contact with the plates, should not exceed three-fourths of an inch per foot of boiler diameter, and to facilitate inspection it is advisable to have the blocks opposite the ring-seams so arranged that they may be readily removed at cleaning times. The cross bearing-walls at front ends are often built straight across regardless of the blow-off pipe and its connections, and there is thus great danger of these being broken by the movement of the boiler through alternate expansion and contraction. The blow-off pipes and joints are also in some cases exposed to the action of the heated gases in the bottom flues, which has the effect of baking into a solid mass any deposit that may be in the pipe, and consequently will prevent it from operating when required. By recessing the front cross walls round the blow-off pipe, as shown on plan of setting (*Frontispiece*) the pipe is left quite free to adapt itself to any movement of the boiler, and easy access being thus provided, leakage from the joints is readily detected and stopped before the plates or pipes become impaired by corrosion.

The front end plates of Lancashire or Cornish boilers should always be kept a few inches above the level of flooring plates, and the shell angle iron should be arranged to project over the front bearing-walls so as to keep the rivetted seam clear of the brickwork. Attention to these points will prevent the corrosion so commonly found on the front end plates and angle irons of boilers which are set below the level of the flooring plates, and leakage from the angle-iron seam, unless of a serious nature, can be stopped without incurring the trouble and expense of removing an amount of brickwork. Corrosion at and about the front end plates is frequently caused by the ashes from the furnaces being slaked on the foot-plate—a practice which, to say the least, is one that betokens an utter disregard for the appearance and durability of boilers, and cannot be too strictly forbidden.

The fire bridges in the furnaces of internally-fired boilers often cover rivetted seams, and considerable surfaces of the plates at the under sides of furnace tubes, with the result that these parts are liable to be dangerously thinned by corrosion, unless the brickwork is removed periodically for examination. These bridges should not exceed 9 inches in width ; and, as in the case of bearing-walls and other parts in contact with the plates, fire-clay instead of lime should be used in their construction.

Cast or wrought-iron bearers are sometimes fitted in the furnaces of boilers for supporting the fire bridges, and this practice, inasmuch as it removes the liability to corrosion, is well worthy of being more generally adopted.

The method of enclosing the upper plates shown on Fig. 7, whilst advantageous as a covering to prevent loss of heat by radiation, also permits of them being examined at cleaning times without inconvenience or expense, but the first cost of this arrangement is considerable, and is against its coming into general use. The necessity for baring the tops of boilers at intervals to ascertain the condition of the plates, is now very generally recognised, and in view of this the non-conducting covering should be made light and suitable for removal. The heavy brickwork and flagging sometimes used for this purpose are low in non-conducting power as compared with other materials, and apart from the trouble and expense of removing them when required, they are very liable to harbour moisture from leakage without showing any indications of its existence on their outer surfaces.

The various points in connection with the settings of boilers referred to in the foregoing are all of more or less importance in regard to corrosion. It should, however, be remembered that although the situation of a boiler is free from dampness, and its setting arranged on the best prin-

ciples, it is still liable to be impaired by leakage or other defects, and that to prevent deterioration and accident careful periodical examination is absolutely necessary.

Leakages of all kinds should be stopped with the least possible delay, as, however slight they may be, corrosion is sure to follow, and many of the most serious corrosions have been traced to neglect of what are sometimes termed "simple leakages." The greatest attention should be given to leakage and corrosion at and about the longitudinal seams, inasmuch as they, to begin with, are the weakest parts of the structure, and are consequently less able to afford any further reduction of strength. These seams should always be arranged so as not to come in contact with the brickwork at any part, and they should be kept as much as possible from the direct action of the gases in the flues. Serious corrosion is sometimes caused through the soot and ashes which collect in the flues being allowed to remain in contact with the plates after they are cold. For this reason, when it is intended to lay a boiler off for a length of time, the flues and plates should be thoroughly swept; and as a prevention of internal corrosion, when boilers are out of work, they should be filled quite full of water, into which a quantity of common soda has been dissolved. During the winter season, however, care is necessary to prevent injury by frost.

IV. EXPLOSIONS CAUSED BY DEFECTIVE DESIGN AND CONSTRUCTION.

The number of explosions accounted for by defects in design and construction, is very much in excess of what might be expected, considering what is known regarding the strength of materials, and the forms of construction best adapted to secure safety and durability.

Unsupported flue tubes, unstrengthened man-holes, defective staying, and weakness induced by malconstruction, are the causes which have led up to the explosions referred to in the reports under this head, and it may be of interest to consider each of these shortly.

(1.) UNSUPPORTED FLUE TUBES.

Collapse of the furnace tubes of Cornish and Lancashire boilers is a very common source of accident, and is frequently attended with serious results. It may, as already explained, be due to the metal of the tube becoming weak through overheating, but it is also at times the result of structural weakness; it being no uncommon occurrence to find boilers working at pressures dangerously near the ultimate strength of their furnace tubes. The shells of these boilers may be found equal to a bursting pressure of 500 lbs. per square inch, whilst the furnace tubes would collapse at one-fifth of the same pressure. Such practice in boilermaking, which has been compared to chains made up of five and one ton links alternately, is happily becoming rarer, and it is to be hoped that not only will it cease in the case of new boilers, but that all boilers presently in this condition will be replaced, or have the furnace tubes strengthened so as to make them safe.

The effect of pressure exerted against the internal surface of a cylindrical vessel is to preserve its true form, and to restore any departure therefrom, such as may be due to malformation, &c.; but, on the other hand, when a cylinder like the furnace tube of a boiler is exposed to external pressure, the tendency of the pressure is not to restore, but to still further increase any deviation from a perfectly cylindrical form. This quality of the cylinder in reference to external pressure is of the utmost importance when it is

considered that all furnace tubes, however skilfully manipulated, deviate more or less from the truly cylindrical form, and that they are subject to still greater deviations when under working conditions. In these circumstances, it will be apparent that the strength of a flue to resist external pressure cannot be determined by the rules which would apply to a perfectly cylindrical vessel of uniform thickness and strength throughout, and that careful experiment, combined with the experience obtained from investigations of collapsed flues, are the only means whereby fairly reliable data can be obtained.

The formula commonly used for this purpose, is that deduced from the experiments of Sir William Fairbairn, and although these were somewhat limited, and made for the most part upon flues of much smaller dimensions than are now generally in use, the results of experience since they were made go to show that this formula is sufficiently reliable, if due regard be given to the quality of material and workmanship. There are various other formulæ for computing the collapsing pressure of long flue tubes, and whilst several of these have had the benefit of more complete investigation, as well as later experience, there are none simpler or more in accord with actual results than that of Fairbairn's. According to this formula, which is given on page 49, the strength of a flue tube to resist collapse varies directly as the 2·19 power of the thickness of the plate, and inversely as its diameter and length. In applying this rule, it will of course be understood that the material and workmanship are of good quality, and that the flues are as nearly circular as can be made with lap joints.

By butt-jointing or welding the longitudinal joints of flues they can be made more nearly cylindrical, and consequently stronger than when lap-jointed.

As stated elsewhere, there are instances to be met with

wherein the flue tubes of certain boilers have worked without accident for years, although, according to Fairbairn's formula, the pressure they daily sustain is dangerously near that at which they would collapse, and the margin of safety is considerably below what general experience has shown to be safe. The Board of Trade Reports, and other records of boiler accidents, furnish many examples in proof of the necessity that exists for so constructing flue tubes as to insure a large margin of safety against collapse; and although instances are met with wherein small margins have sufficed for years, it only goes to show that these boilers have been well cared for, and have hitherto been exceptionally free from such shocks in working as the majority of boilers are exposed to.

Figs. 12, 13, 14, 17, and 18 are illustrations of the various methods adopted for increasing the strength of flue tubes.

Fig. 12 represents what is known as the "Adamson's flanged seam," and is a form of jointing largely used for the flues of high-class boilers. This joint imparts great resistance to collapse, and, as will be seen, there are no rivet heads, plate edges, or double thicknesses of plate exposed to the direct action of the furnace gases.

Fig. 13 represents the solid flanged anti-collapsing hoop as now made of steel from $\frac{5}{16}$ inch to $\frac{3}{8}$ inch in thickness. These hoops have been found to act very satisfactorily in the matter of strengthening flue tubes, and although the opinions sometimes expressed regarding the elasticity they impart may be exaggerated, there can be no doubt that they are serviceable in relieving the straining at the ring seams consequent upon the arching of the flues through unequal expansion. Like the ordinary lap joint, these hoops have the disadvantage of entailing a double thickness of plate; but this has not proved a serious objection, or prevented them from being extensively used.

Fig. 14 represents a flue having the rings of plating united by ⊥ iron hoops, which is a form of jointing that has given place to the more improved methods already described.

Fig. 17 is an illustration of the means employed for strengthening flue tubes which have originally been constructed of a series of plain rings of plating with ordinary lap joints.

It will be seen that the method referred to consists of angle-iron rings which are put on in halves, the ends being closely butted together, and secured at the joints by double straps, having two rivets at each side of the joints. These rings are made from 2 inches to 2½ inches larger in diameter than the flue tubes to which they are attached, so as to avoid a double thickness of plate. The rivets securing them should be spaced about 6 inches apart, and the holes in the ferrules should be made to fit the rivets as exactly as possible. An objection frequently urged against this method of strengthening the flues of old boilers, is the difficulty of preventing deposits from collecting in the water spaces, and thereby causing overheating and probable fracture of the plates, but except where "Galloway" tubes can be inserted advantageously there is no other remedy for weak flues, and in any case it is certainly more judicious to fit these rings, and take precautions for keeping the water spaces clean, than to risk total collapse without them.

In single-flued boilers the distance between the bottom of the flue and the shell is sometimes too confined to admit of angle-iron rings having the usual water spaces between them and the plates; but when this occurs the rings may be rivetted *close to the bottom* of the flue, provided the boilers are fired in the ordinary manner. In the case of boilers fired by gas a clear space all round the strengthening ring is necessary to prevent overheating, the bottom of the flue

Fig.12.

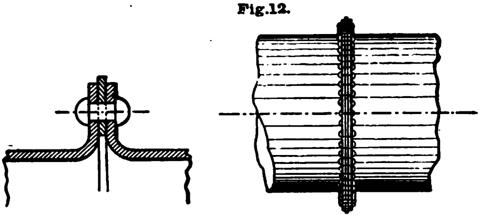


Fig.13.

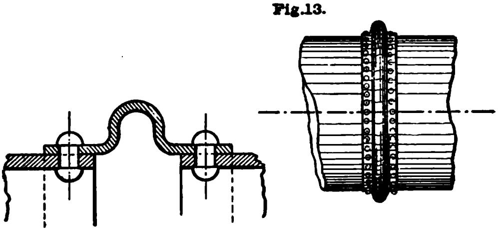


Fig.14.

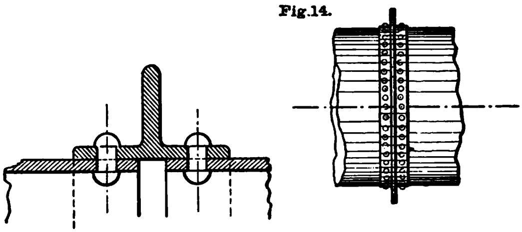


Fig.15.

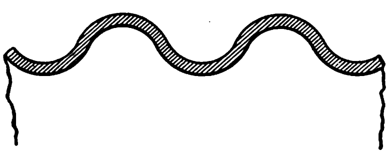


Fig.16.

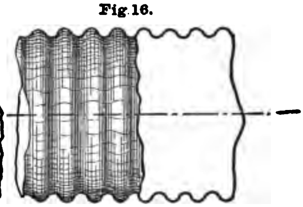
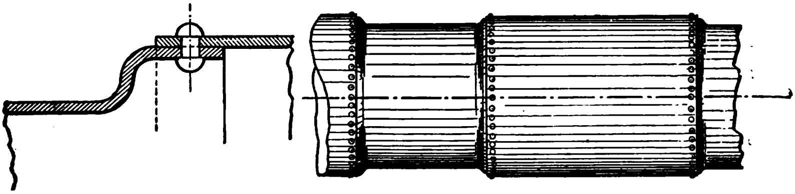


Fig.19.



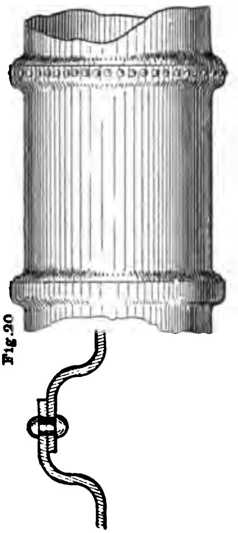


Fig.20

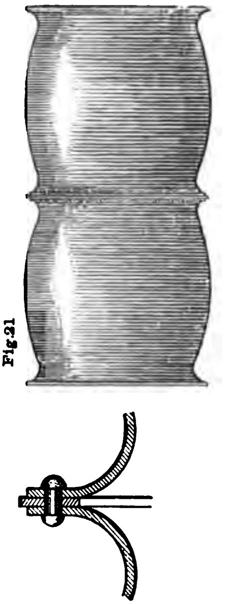


Fig.21

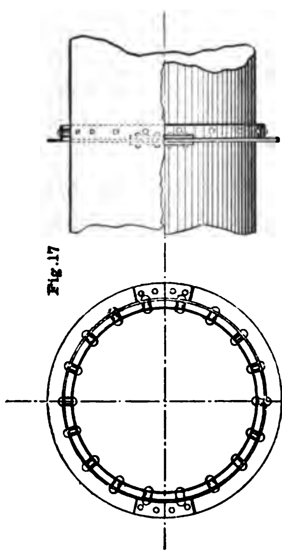


Fig.17

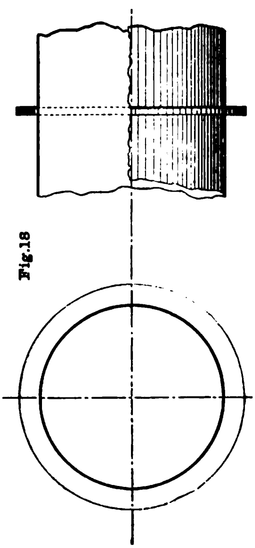


Fig.18

in such boilers being much hotter than those fired in the usual way by hand.

Figs. 19, 20, and 21 are modern designs of flue tubes which are deserving of favourable consideration. One of the special features of each, like those already referred to, is that the mode of jointing the rings of plating together, imparts considerable strength in the direction of collapse, and so far as can be judged from the time they have been at work, they are entitled to the claims of durability and efficiency made by the respective inventors.

Fig. 18 is a cross and longitudinal section of a method for strengthening flues which is now very rarely adopted, its failure to prevent collapse having been frequently experienced. A series of rings like that shown is simply shrunk on to the flue, and it was assumed that as these rings would prevent distortion, collapse could not occur. In the case of a truly circular flue-tube built of metal, having a uniform thickness and strength, this reasoning might apply to a certain extent, but such perfection is impracticable, and even were it otherwise, the equilibrium would be destroyed under working conditions, and in the event of overheating or corrosion occurring, these unattached rings would be of no service in limiting the damage that would result from collapse.

Figs. 15 and 16 are respectively a longitudinal section and an elevation of a corrugated ring, such as is now extensively used in forming the furnace tubes of marine and land boilers. Flues made up of corrugated rings are much stronger in the quality of resisting collapse than any of the others, and from the experience of a number of instances, it is evident that they are less liable to rupture in the event of serious overheating through shortness of water. Objection has been taken to corrugated flues for land boilers on the ground that they do not support the front and back end

plates in the same effective manner as those made up of plain rings. Their appearance is, perhaps, suggestive of some such objection, but the results of a series of tests by the makers, and the absence of any indications of weakness in a number of boilers examined, go to show that corrugated flues are not inferior in this respect to other forms of good construction, and that they are quite reliable as end-plate stays up to the highest pressures at present employed.

In calculating the strength of a flue tube which is fitted with strengthening rings, the greatest distance between any of these represents L in the formula, or, what is the same thing, the portion of flue between any of the strengthening rings, or between the end plates and nearest rings, is treated as if it were a separate flue effectively supported at its ends. For example, the collapsing pressure of a flue tube, 30 feet long by 3 feet in diameter, and $\frac{3}{8}$ inch thick, is 87 lbs. per square inch; but if such a flue be fitted with a substantial strengthening ring at the centre, it is then treated in the calculation as if its length (L) were 15 feet, and is consequently found to have double the strength, the collapsing pressure being 174 lbs. In the same way, if two rings be equally distributed over the length of the tube the greatest distance, or L in the formula, would be 10 feet, and the collapsing pressure would be increased accordingly.

It may be argued from what has been said that flue tubes constructed throughout of Adamson's flanged rings, or fitted at each joint with solid flanged hoops, are unnecessarily strong, and out of proportion to other parts of the boilers to which they belong. There is no doubt that in many instances this is really the case. It is, however, well to bear in mind that boilers so constructed usually carry very high pressures, and in the event of the flue crown plates being bared and softened by overheating, the strength imparted by these joints would in all likelihood prevent

rupture and serious explosion, and, as a matter of fact, this is really what has been experienced in a number of cases.

In addition to the various methods of strengthening flue tubes explained, the "Galloway" cross tube (which is now so generally in use) is a material aid in the same direction. There is no doubt that the principal advantages of these tubes are increased heating-surface and improved circulation; and although it must be granted that as supports they are inferior to flanged seams or encircling hoops, they have frequently been found of the greatest service in limiting the damage and preventing explosion in cases where the flues had become softened through overheating from shortness of water. In the absence, however, of reliable data to determine the collapsing pressure of flues strengthened by cross tubes only, the support obtained from these should not be relied on to any great extent; and even in the case of flues which have been fitted with cross tubes to the best advantage, the calculated collapsing pressure should be at least three times the working pressure, or, in other words, such flues should have a factor of safety of 3 against collapse, independently of any support afforded by the tubes.

As already explained, the strength of a cylinder exposed to external pressure, such as a flue, varies directly as the 2·19 power of the thickness of the plate; whereas the strength of a cylinder subjected to internal pressure, such as a boiler shell, varies simply as the thickness of the plate. This will be readily understood by reference to the tables of collapsing and bursting pressures on pages 50 and 93. It will be seen that the bursting pressure of a shell, say 6 feet diameter, made up of $\frac{1}{2}$-inch plates, is exactly twice that of a shell of the same diameter made up of $\frac{1}{4}$-inch plates. In the case of a flue, however, exposed as it is to external pressure, reference to the table will show

that an alteration of the thickness of the plates affects its strength in a much greater degree. Thus, a tube 28 feet long by 33 inches diameter, made up of plates ½ inch thick, has an ultimate strength to resist collapse equal to 190 lbs. per square inch; whereas a flue of similar length and diameter, made up of ¼-inch plates, would collapse under a pressure of 42 lbs. per square inch. It will thus be seen that in the event of a boiler shell being reduced by corrosion to one-half its original thickness, its strength to resist rupture is only reduced to the same extent; whereas a flue under similar conditions would have its ultimate resistance to collapse reduced by four and a half times—thus, $28 \times 33 = 924 = 42$ lbs.

The great loss of strength that may be caused by corrosion, combined with varying conditions of temperature, &c., to which the plates of flues are exposed even in ordinary working, renders an ample margin of safety necessary, and in no case is it judicious to have plain flues sustaining pressures exceeding one-fourth of their calculated strength.

COLLAPSING PRESSURES.

Fairbairn's rule is, $P = 806300 \times \frac{t^{2\cdot19}}{L \times D}$. Where

P = collapsing pressure in lbs. per square inch,

D = dia. of flue in inches, L = length of flue in feet,

and t = thickness of plate in inches.

TABLE OF 2·19 POWERS FROM ¼ INCH TO ½ INCH.

Thickness of plate,	¼"	5/16"	⅜"	7/16"	½"
,, ,,	·25	·3125	·375	·4375	·5
Power 2·19, . .	·048027	·078294	·116715	·163583	·219151

TABLE OF COLLAPSING PRESSURES.

To find the collapsing pressure of a flue by the following table, multiply the length of the flue in feet by its diameter in inches, and opposite the nearest number to the product (under the proper thickness) will be found the collapsing pressure approximately, thus—Flue 27 feet long, 34 inches diameter, made of $\frac{3}{8}$-inch plates, $27 \times 34 = 918$, opposite 920 in the $\frac{3}{8}$-inch column is found 102 lbs. = collapsing pressure.

L × D	Collapsing pressure in lbs.					L × D	Collapsing pressure in lbs.					L × D	Collapsing pressure in lbs.				
	$\frac{1}{4}''$	$\frac{5}{16}''$	$\frac{3}{8}''$	$\frac{7}{16}''$	$\frac{1}{2}$		$\frac{1}{4}''$	$\frac{5}{16}''$	$\frac{3}{8}''$	$\frac{7}{16}''$	$\frac{1}{2}''$		$\frac{1}{4}''$	$\frac{5}{16}''$	$\frac{3}{8}''$	$\frac{7}{16}''$	$\frac{1}{2}''$
360	107	175	261	366	491	620	63	101	152	212	286	880	44	71	107	149	200
380	102	166	247	347	465	640	61	98	147	206	276	900	43	70	104	146	196
400	97	158	235	329	441	660	59	95	142	200	267	920	42	68	102	143	192
420	92	150	224	314	420	680	57	93	138	194	259	940	41	67	100	140	188
440	88	143	214	299	401	700	55	90	134	188	252	960	40	65	98	137	184
460	84	137	204	286	384	720	53	87	130	183	245	980	39	64	96	134	180
480	80	131	196	274	368	740	52	85	127	178	238	1000	38	63	94	131	176
500	77	126	188	263	353	760	51	83	123	173	232	1020	38	62	92	129	173
520	74	121	181	253	340	780	50	81	120	169	226	1040	37	60	90	126	170
540	71	117	174	244	327	800	48	79	117	164	220	1060	36	59	88	124	167
560	69	113	168	235	315	820	47	77	114	160	215	1080	35	58	87	122	164
580	67	109	162	227	304	840	46	75	112	157	210	1100	35	57	85	120	161
600	65	105	157	219	294	860	45	73	109	153	205	1120	34	56	84	118	158

Example.—Find the collapsing pressure of a flue 33 inches diameter, 28 feet long, and $\frac{3}{8}$ inch thickness of plates.

The value of $\frac{3}{8}$ inch raised to the 2·19 power is ·116715 (see Table, p. 49).

Then $806300 \times \frac{\cdot 116715}{33 \times 28} = 101 =$ the collapsing pressure in lbs. per square inch.

(2.) UNSTRENGTHENED MAN-HOLES.

The primary ruptures of not a few explosions have been traced to fractures at the unstrengthened edges of man-hole openings, and apart from such serious results, numerous cases of expensive stoppages and repairs could be quoted as having been due to the same cause. Whilst such experience points to the necessity of making adequate compensation for the plate section removed for man-holes, it has not been so generally acted on as could be desired, there being still a considerable number of boilers, the man-holes of which are not fitted with suitable strengthening rings.

Man-hole openings are most commonly elliptical, this form being well adapted for the purpose, and at the same time requiring less of the material to be cut away than that of any other practicable form. These openings in land boilers are most frequently arranged with the greater diameter running longitudinally, whereas, if maintaining the strength of the shell were the only consideration, they should be cut with the greater diameter running circumferentially. The reasons usually assigned for this departure from sound constructive principles are, that openings thus arranged are more convenient for ingress and egress in the usual types of boilers, and that the joints are more easily kept in order—this, of course, refers to cases where the man-

hole doors are cambered and jointed directly to the boiler plates. It is sometimes argued, that as the strength of the material left after the man-hole is cut out is equal to, or greater than, that of the section of the solid plate at the longitudinal joints, there is no need for compensating rings or frames; but, whilst this may apply in some instances, there are many where, owing to narrow plates, or to the position of the openings, the plate section remaining is so limited as to reduce the ultimate strength of the boilers to a dangerous extent. Apart altogether, however, from the weakness thus caused, it should be borne in mind that the unsupported edges in addition to the straining due to internal pressure, are also subjected to serious stress by the frequent breaking and renewing of the man-hole joints. The most careful and gradual tightening of the jointing cannot prevent more or less unequal straining round the plate edge, and when the operation is performed by careless or unskilful hands, the stresses on certain portions must frequently be greatly in excess of that due to the steam pressure. There is also the likelihood, if not probability, of the plate being further reduced by corrosion through leakage from the joint.

Man-hole openings may be effectively compensated for by rivetting round their edges wrought-iron or steel rings of such dimensions as will make them equal to the plate section cut away. These rings and man-hole lids should be of substantial make, and if rivetted, as shown by Figs. 22 and 23, the joints with ordinary attention can be made quite tight and durable. In making the man-hole joints—as with all joints—care should be taken to ascertain that the surfaces are clean, and the jointing used free from grit or other matter likely to prevent its being uniformly tightened. When leakage does occur, it may be put down to some distortion of the plate, or to portions of the jointing

giving way, and in either case the "screwing up" usually resorted to is more likely to increase the evil than to act as a remedy, and there is considerable danger of the plate being fractured.

Fig. 22

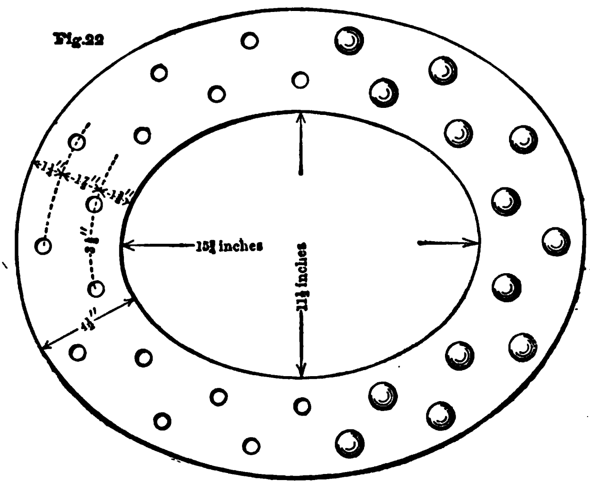
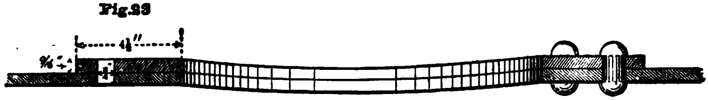


Fig. 23



Man-hole frames of various sections, and made as required of cast-iron, cast-steel, or wrought-iron, are now very commonly applied to land boilers, and unless in those of small diameter, or in types where they would hamper ingress and egress, they should always be fitted in preference to the ordinary stiffening rings already described.

(3.) DEFECTIVE STAYING.

In staying the flat surfaces of boilers it is usual, in good practice, to make the stay section equal to a load five or six times in excess of that to which the boilers are subjected, the strength due to the thickness of the plates, and the support afforded by the attachments at their edges, being left out of consideration.

The actual resistance which a flat plate offers to pressure is difficult to determine by calculation, but by experiment it is known that the ends of Lancashire or Cornish boilers and other plates under like conditions—unless supported by stays—would require to be of excessive thickness to prevent buckling at even the most moderate pressures in daily use.

Dished or cambered plates, such as those used at times to form the ends of plain cylindrical boilers or the crown plates of vertical boilers, are better designed to resist the tendency to buckling, all the more so the nearer they approach the hemispherical form; but even with these, except when of small area, and exposed to moderate pressures, stays are found to be necessary.

Flat and partially rounded surfaces should therefore be avoided as much as possible in the construction of boilers, for although they can be made of equal strength to the cylindrical and spherical parts (usually termed self-supporting) the stays required to effect this are liable to impede circulation or collect deposit, and in most cases they are an inconvenience to cleaning and repairing.

The simplest form of boiler—viz., the plain cylindrical with hemispherical ends—may be considered as the type which of all others is best designed to render the application

of stays unnecessary;* but the limited heat-absorbing surface of this boiler, combined with the necessity for economising fuel and space, has led to the more general adoption of other types better calculated to attain rapid generation of steam with economy. It must be granted, however, that these advantages are secured at a sacrifice of simplicity in construction, and with the result that, in the majority of boilers, there are certain parts more or less of weak form which require to be supported with suitable stays. Amongst these the Lancashire Multitubular and Locomotive are the types most generally in use, and the methods of staying the flat surfaces rendered necessary is well worthy of consideration.

(*a.*) **Lancashire and Cornish Boilers.**—The greater portion of the end plates of these boilers are effectively supported by the internal flue tubes, and it only remains that the parts above and below these tubes should be stayed, so as to make the ends of proportionate strength to that of the boilers in other respects. The forms of staying employed for this purpose are gusset plates, longitudinal, and diagonal bar stays, and of these the gusset-plate stay is most commonly applied. Longitudinal bar stays to be reliable must be fitted with the utmost care, particularly in boilers of maximum length. If screwed up tightly, they prevent the end plates from springing to accommodate the expansion of furnace tubes, and in such cases deterioration by leakage and grooving is certain to occur. The difficulty of determining the length of the longitudinal stays, so as to allow for the expansion of the flues, and the inconvenience which they present to cleaning and repairing, are the principal objections to their

* There are cases where, under certain conditions of working, it is advisable to have substantial stays extending between the ends of this type of boiler, but the reasons for so doing are outside of the present consideration of the subject of stays.

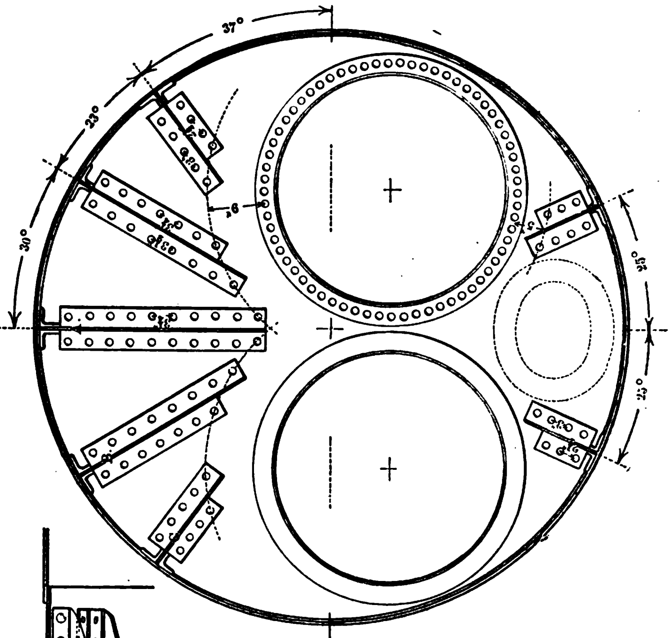


Fig.25 Cross Section. Front end.

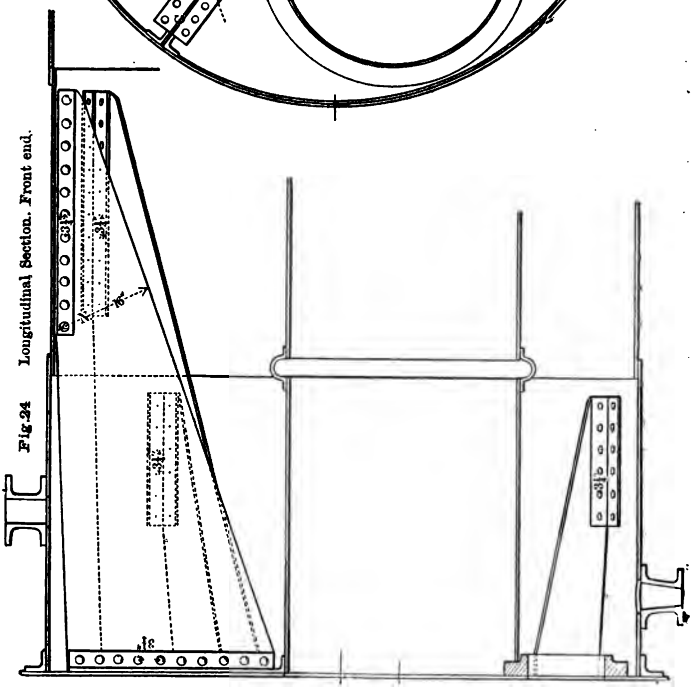


Fig.24 Longitudinal Section. Front end.

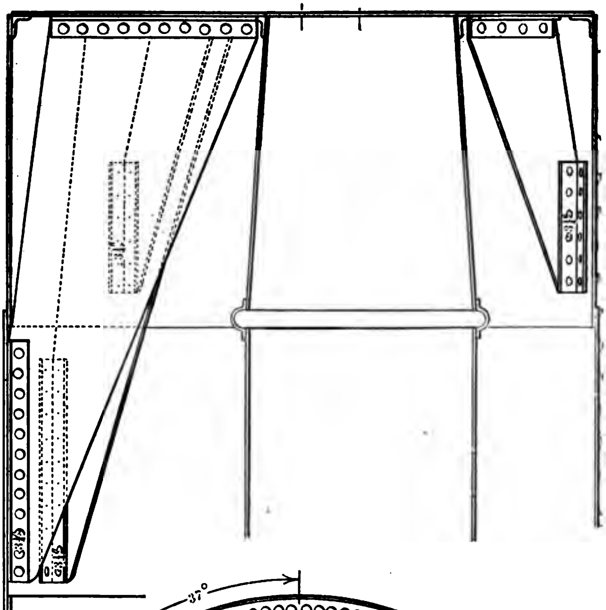


Fig. 27 Longitudinal Section. Back end.

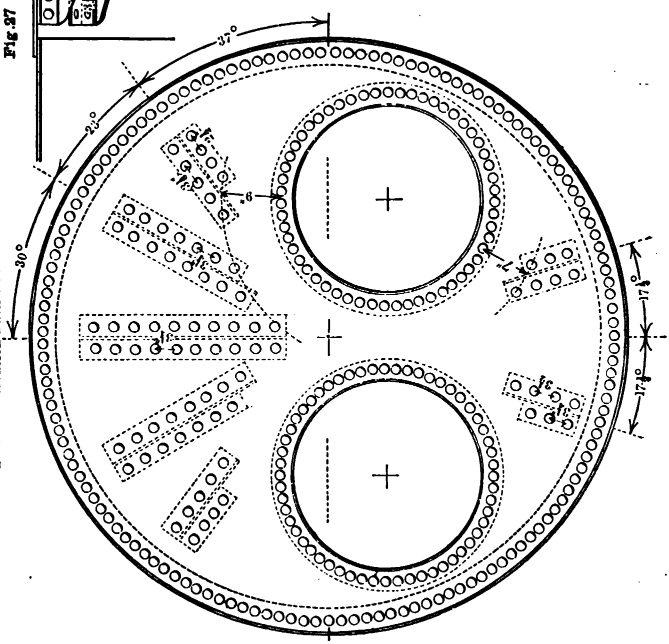


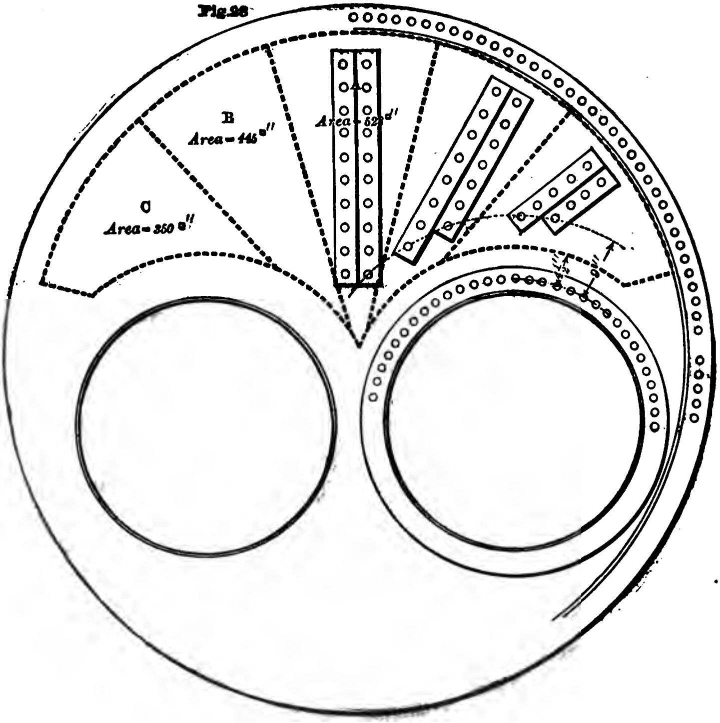
Fig. 26 Elevation Back end.

use. For high-pressure Lancashire boilers they are frequently used in combination with gusset stays, but in good practice they are, as a rule, applied to act more as a "stand by,"—to take their share of the strain in the event of any of the other stays failing. Longitudinal stays in all cases should be secured at the ends by substantial nuts and washers, both internally and externally, and except in very short boilers they should be supported by suitable rods or brackets *rivetted* to top of shell. Diagonal bar stays are inferior to gusset-plate stays, inasmuch as they do not support the ends in the same uniform manner, and are not so well adapted to resist the upsetting action due to the indirectness of the strain. Figs. 24, 25, 26, and 27 are illustrations of the ends of a Lancashire boiler fitted with gusset-plate stays suitable for a working pressure of 80 lbs. per square inch, and Fig. 28 represents the area supported by each stay. It will be seen that three of the stays are carried back to the second ring of shell plates, which adds considerably to their efficiency without interfering with accessibility to any great extent. The portion of the end plates above the flues requiring to be stayed is (as is usual) about one-third of the total surface, and the shell being 7 feet 6 inches diameter, there is thus an area of 2,120 square inches over which the stays have to be distributed. The strength due to the plates and their edge attachments is left out of consideration, and the stay section in this case has been made ample for the pressure to which the segment of the plates above the flue is exposed. The actual load on the plate is found by multiplying the pressure in pounds per square inch by the number of square inches in the area—viz., $80 \times 2{,}120 = 169{,}600$ lbs.; and as the strains to which stays are exposed should not exceed 5,000 lbs. per square inch of sectional area for iron, and 7,000 lbs. for steel, the total sectional area required by these stays is found by dividing

169,600 by 5,000 and 7,000 for iron and steel, which gives 34 and 24 square inches respectively. It will of course be understood that the rivet section at each end of the stay is greater than the gusset plates section at their weakest parts, marked N on Fig. 24.

In the illustrations the proportions are made out for steel, the thickness of the gusset plates being $\frac{7}{16}$ inch.

Fig. 28



Breadth of Stays—

Stay A	at narrowest part of web		is 15½	inches net.
Stays B	„	„	are 13	„
„ C	„	„	10	„

Areas for each Stay—

Stay A supports an area of 528 square inches.
Stays B „ each an area of 445 „
„ C „ „ „ 350 „

Pressure per square inch of stay section $= \frac{A \times P}{D \times t}$, where A = area to be supported, P = pressure, D = depth of stay at weakest part, and t = thickness of stay plate. Then

$$\frac{528 \times 80}{15\frac{1}{4} \times \frac{7}{16}} = 6{,}332$$ lbs. per sq. in. of stay A plate section,

$$\frac{445 \times 80}{13 \times \frac{7}{16}} = 6{,}260$$ „ „ stays B „

and

$$\frac{350 \times 80}{10 \times \frac{7}{16}} = 6{,}400$$ „ „ „ C „

Total area supported by gusset stays above the internal tubes is $528 + (445 \times 2) + (350 \times 2) = 2{,}118$ square inches, which is $\frac{2118}{6361}$, or nearly $\frac{1}{3}$ of the whole area of end plate.

Total sectional area of stays—A, $15{\cdot}25 \times {\cdot}4375 = 6{\cdot}67$
B, $13 \times 2 \times {\cdot}4375 = 11{\cdot}37$
C, $10 \times 2 \times {\cdot}4375 = 8{\cdot}75$

$26{\cdot}79$

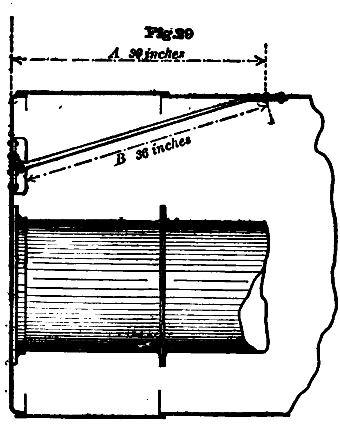
As will be seen from the foregoing, the proportions of these stays are ample, the greatest strain being considerably under the allowable stress of 7,000 lbs. per square inch of section at the weakest parts. It may be argued that the outer stays, C, cannot support effectively the irregular area shown on the diagram, but the portions of the plate which might be considered outside the influence of these stays, are well supported by the shell and flue attachments, and

are stiffened by the feed- and scum-pipe blocks which are usually rivetted at these parts. The gusset stays below the flues are proportioned somewhat similarly to the others; but owing to the man-hole opening, those at the front end cannot be placed so advantageously as at the back end. The plate, however, is stiffened by the compensating frame round the edge of the man-hole, and there being no necessity for a breathing space at bottom, such as there is at the upper sides, the angle irons can be carried much nearer the flues, and by this means the gusset plates can be made of sufficient depth.

Gusset stays are often very imperfectly applied, the angle-irons connecting them to shell and ends being slovenly fitted with bolts, and frequently set so as to leave more or less of an open space when the plates are inserted between them; the plates may also be found warped and bent into various forms owing to the stays not being arranged radially; and in addition to such defects in design and workmanship, instances are not wanting where the strength of stays, even if adequately fitted, is considerably under what is required, the result being that the attachments to shell and flues groove rapidly by the excessive springing of the plates. Grooving will also be caused by too rigid staying, such as occurs when the gusset angle-irons on the end plates are brought down close to the flue attachments. Referring to Figs. 25 and 26, it will be seen that there is a distance of 9 inches between the bottom rivets of the gusset stays, and the rivets at upper sides of furnace angle-irons. This space (commonly termed the "breathing space") admits of the plates springing to a moderate extent, and thereby prevents undue straining, such as is liable to occur through the greater expansion of the furnace tubes over that of the shell. With boilers carrying moderate pressures, the ordinary practice is to fit the gusset plates into the angle-irons after the end plates have been rivetted up—this method being

more convenient, and the breadth of the gusset plates being such that they can be passed through the man-holes. With Lancashire boilers, however, as now commonly constructed for working pressures from 60 to 90 lbs. per square inch, the gusset plates required are too deep to pass through the man-hole openings, and it is therefore necessary that they should be fitted to the shell angles before the end plates are put on. The extra work this entails is trifling, compared with the greater efficiency of the stays, yet new boilers of maximum size and intended for high pressures may occasionally be seen in which the gusset stays do not exceed 15 inches at their greatest depth, although the angle-irons by which they are united to the end plates may have a depth of 30 inches or more.

When diagonal bar stays are used, the sectional area should be proportionally greater than that of horizontal or direct stays, the rule for determining this being as follows:—



"Having found the area required for a direct stay, multiply the same by the length of the diagonal stay, and divide the product by the length of a line drawn at right angles to the surface supported to the end of the diagonal stay, and the quotient will be the area increased to what is required."

Referring to Fig. 29, if the horizontal distance, A, is equal to 30 inches, and the diagonal stay, B, has a length of 36 inches, the additional area required by the latter in excess of a direct stay may be found by reducing proportionately the stress limit of the material thus—*for iron*, as 36 inches

is to 30 inches, so is 5,000 lbs. to 4,166 lbs. per square inch of section; and *for steel*, 36 inches : 30 inches : : 7,000 lbs. : 5,833 lbs. per square inch section. For diagonal stays, then of the length given the calculation would be the same as for direct stays, except that the stress limit or constant would be reduced as explained.

(*b.*) **The Breeches-Flued Boiler.**—This boiler, in so far as the construction of the shell and end plates is concerned, is similar to those of the Lancashire type; it differs, however, in the arrangement of the internal flues; by the formation of these additional flat surfaces are introduced, which, like the end plates, require to be supported by suitable stays. Figs. 30, 31, and 32 are illustrations of the furnaces and flue, from which it will be seen that the two furnaces only extend for a short distance, and that at their extremities they are connected with a single flue tube. The principal object of this arrangement was the prevention of smoke, which it was claimed would be secured by alternate firing of the furnaces.

The connection between the two furnaces and the single flue, commonly called the "Breech" or combustion chamber, is necessarily of weak form; for, whilst the sides are circular, the top and bottom plates (as shown by cross-section, Fig. 32) are nearly flat, and, to prevent undue deflection or collapse, require to be stayed. ⊥ or L iron bars have been used to stiffen these plates, and there are still a few old boilers of this type, the combustion chambers of which have no other provision. As high steam pressures became more common, however, the numerous collapses that occurred made it apparent that something more than mere stiffening of the combustion chamber plates was required, and to this end stays of various sections were fitted between the flat surfaces of combustion chamber and the top and bottom shell plates. This method of staying, although fairly successful

in preventing collapse, has the disadvantage of impeding the expansion of the furnaces and flue, and thereby induces local straining more or less severe, which renders frequent

Longitudinal Section. Elevation.

Fig.30

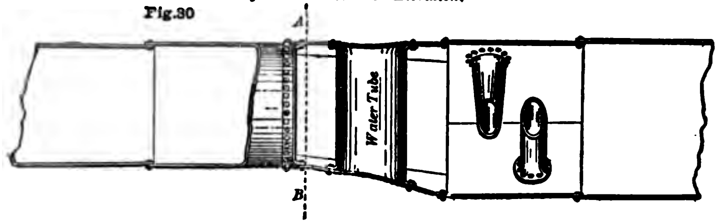


Fig.31

Longitudinal Section. Plan.

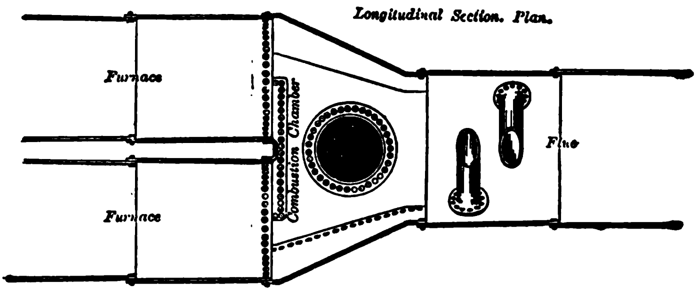
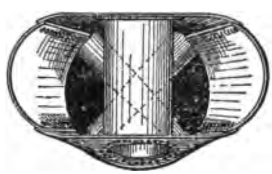


Fig.32 *Section through A. B.*



repairs necessary. In boilers of modern construction, the objections referred to are got over by fitting substantial water tubes between the top and bottom plates of the com-

bustion chamber. These tubes not only act as effective supports, but add materially to the heating surface and circulating power of the boiler.

The Galloway Flue, which throughout its entire length has a cross-section somewhat similar to that of the combustion chamber (Fig. 32), is also supported by a series of water tubes, commonly known as "Galloway's cross tubes."

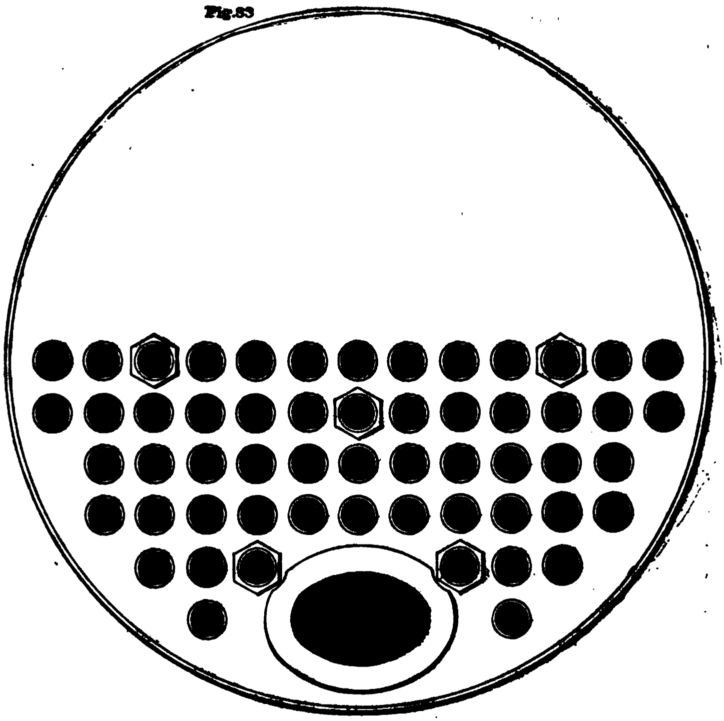
(*c*.) **The Multitubular Boiler.**—The portions of the ends of these boilers above the tubes may be stayed by gussets, or other forms of stays, in the same manner as those of Lancashire type, the remainder of the flat surface being supported by the tubes and a number of longitudinal stays. In some cases the latter are dispensed with, the holding power of the tubes being considered sufficient to prevent deflection of the end plates, and there are doubtless many instances of boilers being worked successfully with no other provision. The method of securing the tubes to the end plates, however, must always leave considerable doubt as to the actual strain which they would sustain without yielding; and it should be remembered that whatever their efficiency in this respect, it will be reduced by the temperature straining to which they are exposed under working conditions. There are few parts in boiler construction that depend more on the qualifications of the workman than that under consideration. The manipulation of the tube-expander and widening drift is of the greatest importance, and should only be entrusted to thoroughly experienced mechanics. Should the tube ends be insufficiently expanded, they will not only be liable to leakage, but their holding power will be proportionately reduced. On the other hand, if the expanding of the tube is carried to excess, the metal will be more or less destroyed, and with such work there is a likelihood of the bridges or spaces between the tube-holes being fractured. The test of actual work, as already stated, has shown that tubes may be

fitted in such a manner as to render further staying of the tube plates unnecessary. Experiment has also proved that the stress required to draw a well-fitted tube is greatly in excess of that to which it would be subjected under an ordinary steam pressure. At the same time, instances are not wanting wherein the tubes of themselves were found insufficient to support the end plates; and, having regard to the chances of imperfect workmanship and the likelihood of tubes being unduly strained by forced firing and impurities in the feed-water, &c., &c., it is, to say the least of it, a wise precaution to support the tube plates by several independent stays. Longitudinal bar stays are frequently used for this purpose, but owing to the difference of expansion between these and the tubes (particularly when the fires are first kindled), they are very liable to cause straining; for, whilst the tubes are exposed to the direct heat of the furnaces, and are consequently at a considerable temperature, the stays are comparatively cool. This disadvantage is most felt in the case of short boilers, and is often the cause of serious leakage at the tube ends. Bar stays also reduce slightly the available tube area, and for these reasons the end plates of multitubular boilers are now more commonly supported by means of stay tubes. These tubes are made considerably thicker than the others, and, instead of being expanded, are screwed into the plates and secured by nuts inside and outside. As may be gathered from what has been said, there is no hard and fast rule to determine the number of independent stays that should be fitted; but in good practice it is customary to arrange the number and strength of the stays, so that, if required to carry the total load due to the pressure on the plates, they would not be subjected to a strain greatly in excess of stays under ordinary conditions.

Fig. 33 represents the end of a multitubular boiler 6 feet in diameter, the upper half of which, as already

explained, may be supported by gusset plates or other forms of stays. In the lower half there are 56 tubes of 4 inches diameter, five of these are steel stay tubes, and their combined strength is such, that if subjected to the total load

Fig. 83



on the tube plate surface, the stress would not exceed 10,000 lbs. per square inch of section. The surface of the plate to be supported is equal to one-half of its total area, *minus* that taken up by the tubes, thus—

Area of half of end plate 6′ dia. = 4071·5 ÷ 2 = 2035·7 sq. in.
„ 4″ dia. tube 12·56 sq. in., 56 tubes, = 703·3 „
„ lower half of end plate exposed to pres., = 1332·4 „

With a steam pressure of 80 lbs. per square inch the total load would be $1332{\cdot}4 \times 80 = 106{,}592$ lbs., which, when divided by 10,000 lbs., shows that the stay tubes require to have a total sectional area of 10·66 square inches. The external diameter of the stay tubes, measured at the bottom of the screw threads at small ends, is taken at $3\frac{7}{8}$ inches, and the internal diameter at $3\frac{1}{2}$ inches. The number of square inches contained in the annular section is found by subtracting the area of the internal diameter from the area of external diameter; thus, $11{\cdot}79 - 9{\cdot}62 = 2{\cdot}17$ square inches; and as the stay area required was found to be 10·66 square inches, it will be seen that five stay tubes of the dimensions given are sufficient to provide a good margin of safety, independent of the staying properties of the other tubes.

When longitudinal bar stays are employed, the number and strength are determined in the same manner, and the rule may be expressed thus, $\frac{A \times C}{P}$, where A is the total sectional area in square inches, C the limit of strain per square inch of section, and P the pressure in lbs. per square inch. The diameter of the stays can be varied to make the number such as will give a suitable distribution over the surfaces to be supported.

(*d.*) **The Locomotive Boiler.**—The tube plates of locomotive boilers are also, as a rule, strengthened by longitudinal stays, these being even more necessary in this boiler owing to the thinness of the tubes, and to the rapid deterioration of their ends, consequent upon the high temperatures to which they are exposed. In a number of instances, steel has been used successfully as a material for locomotive tubes, and there is a likelihood of its ultimately replacing brass for this purpose; at present, however, the majority of makers still use the latter material. The tubes, besides being expanded into the plates in the ordinary manner, are usually fitted with steel

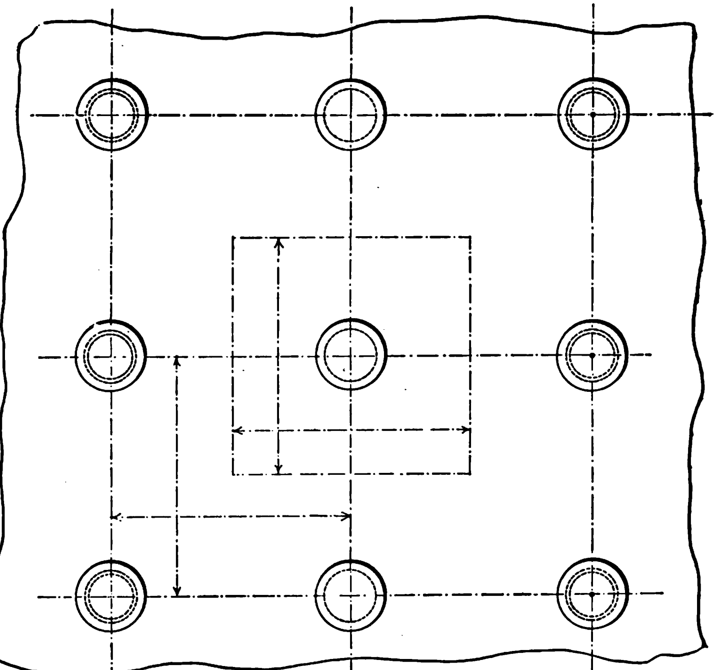


Fig. 35

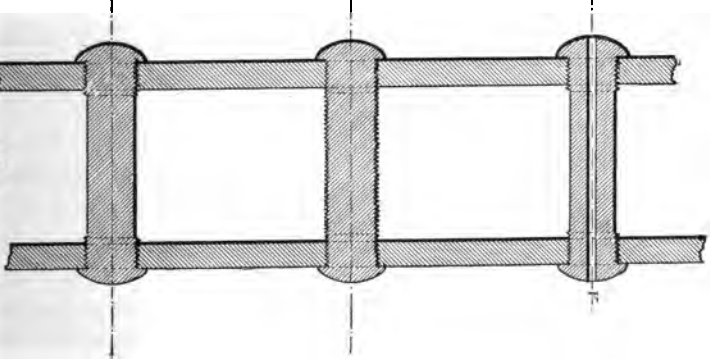


Fig. 34

or iron ferrules—particularly at the firebox ends—which add materially to the strength and durability of the joint. Figs. 34 and 35 illustrate the method of staying the flat sides of the firebox and casing. The stays—commonly termed water-space stays—are screwed through both plates, and are rivetted over at their ends; the body of the stays in the water space being in some cases turned down to the bottom of the screw threads, as shown, which renders them less liable to fracture. These stays are sometimes made of iron or steel, but more frequently of copper, this material being less susceptible to the action of corrosive acids, and generally more durable. Copper stays were also preferred on account of their suitability for rivetting-over cold, but they are not superior in this respect to rivet steel as now manufactured.

In arranging the pitch and diameter of such stays, the strength of the plates is not taken into consideration, and, as explained elsewhere, the practice is to make the stays strong enough to sustain the total load due to the pressure, and to allow for the required margin of safety. The diameters of the stays vary from $\frac{3}{4}$ inch to 1 inch when new, or usually about twice the thickness of the plates. The stays are pitched equally over the entire surface, and it follows that each is subjected to a strain equal to the square of the pitch multiplied by the pressure in pounds per square inch.

The safe stress per square inch of section in this case is the same as in others referred to when iron or steel stays are used—viz., 5,000 and 7,000 lbs. respectively; but when of copper, the working strain should not exceed 4,000 lbs. per square inch of net section.

In the illustrations, Figs. 34 and 35, the stays are proportioned for copper, the pitch being 4 inches. The diameter over the threads is $\frac{7}{8}$ inch, and allowing $\frac{1}{8}$ of an

inch for screw, the body of the stay at the bottom of the screw threads will have a diameter of $\frac{3}{4}$ of an inch, which gives a sectional area of ·44 square inch. The strain that each stay sustains is found by multiplying p^2 by P. Where p = pitch of stays in inches, and P = working pressure in lbs. per square inch, thus—let $p = 4$ and $P = 110$, then $4 \times 4 \times 110 = 1{,}760$ lbs.

The safe load for each stay is found by multiplying A (the sectional area) by S (the safe stress) per square inch of section, which, as explained, should not exceed 4,000 lbs. for copper stays; thus, $\cdot 44 \times 4{,}000 = 1{,}760$ lbs., from which it will be seen that a firebox stayed according to Figs. 34 and 35 meets the requirements.

The following formulæ show how the proportions of the stays may be determined, the values of A, S, p, and P being taken as in the foregoing example :—

(1.) $\dfrac{p^2 \times P}{S} = A$, $\dfrac{4 \times 4 \times 110}{4000} = \cdot 44$ sq. in., sectional area of stay.

(2.) $\sqrt{\dfrac{S \times A}{P}} = p$, $\sqrt{\dfrac{4000 \times \cdot 44}{110}} = 4$ inches pitch of stay.

(3.) $\dfrac{A \times S}{p^2} = P$, $\dfrac{\cdot 44 \times 4000}{4 \times 4} = 110$ lbs. working pres.

With stays of iron or steel the proportions would of course be modified according to the safe stress per square inch of section for each of these materials—viz., 5,000 and 7,000 lbs. respectively.

In addition to the tensile stress due to the pressure on the surface of the plates, these stays are exposed to strains from the unequal expansion of the outer and inner plates, and as a result of these they sometimes break right across, this being all the more liable to occur if the material has been hardened or otherwise impaired by the use of blunt

dies in the process of screwing. The portions of the stays in the water space are frequently found seriously reduced by corrosion and deterioration due to temperature straining. The rivetted ends at furnace sides are liable to be impaired by the action of the fire, and the bulging of the plates which occurs at the stay ends thus affected, tends to widen the holes and cause the plate to slip over, or to strip the screw threads. Deposit to any extent in the water spaces also affects seriously the holding power of the stays, and with the high temperatures usually maintained in locomotive furnaces, there is considerable danger of the plates being ruptured, unless the water spaces (which under the most favourable conditions are necessarily confined) are kept free from accumulation of deposit.

The causes tending to deteriorate the efficiency of firebox stays, as will be apparent, are various, and as their position is such as to render them quite inaccessible to examination, the most careful attention should be given to the working of these boilers.

The comparative immunity from locomotive boiler accidents on the main lines of this country, speaks volumes for the quality of the workmanship and the care that is exercised in keeping them in good order; but amongst those known as contractors' locomotives, and those in use at collieries and iron works, &c., the record is far from being so favourable, and goes to show that stringent measures regarding the cleaning, inspecting, and repairing of such boilers will require to be enforced to prevent, or at least to reduce, the number of explosions and accidents.

With a view to detecting fracturing of the firebox stays, small holes are sometimes drilled through the centre, as shown at A, Fig. 34, the fracture being discovered by the leakage which will occur. Tapping the ends of the stays lightly with a hammer often leads to the detection of

unsoundness, but experience is necessary to make this method of testing successful. Buckling or warping of the firebox plates should be carefully examined, and all leakages from stay ends should be promptly attended to.

The importance of regular washing-out cannot be overestimated, and when the feed-water is of a corrosive nature, a few of the stays should be taken out from time to time to ascertain their condition, which will also to some extent give an idea as to the progress of the corrosion at other inaccessible parts of the boiler. The same precaution should be observed with the tubes, and the whole of the tubes should be taken out at intervals, regulated by circumstances, to admit of thorough examinations being made.

The crown plates of locomotive fireboxes are, as a rule, supported by means of a series of iron or steel girders, which are fitted and connected as shown by Figs. 36 and 37. These figures represent each girder as consisting of a solid bar having holes suitably pitched for receiving the bolt stays, but they are frequently made up of two plates as shown in cross section and plan, Figs. 38 and 39. In fitting girders for this purpose, it is of the first importance that they should be arranged so as to transmit the load directly to the vertical plates; the flanges which unite the roof of the firebox to these plates being kept as free as possible from all strains. Fractures at the roots of the flanges to firebox crowns are by no means uncommon, particularly in the smaller boilers of locomotive type; and although in some instances they may have been induced by rough usage in the process of flanging, they are quite as likely to be the result of badly designed or badly fitted girder stays. The water spaces between the crown plate and bottom of girder should never be less than 1½ inch, and when there is room it will be found advantageous to make them considerably wider. When these spaces are

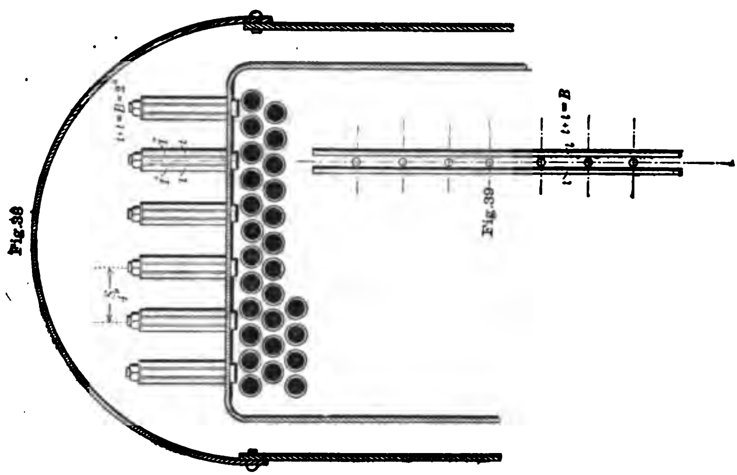


Fig.38
Fig.39
t+t=B

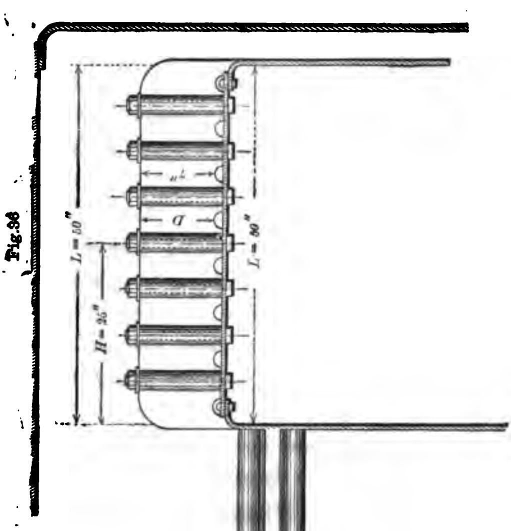


Fig.36
L = 50"
H = 35"
D

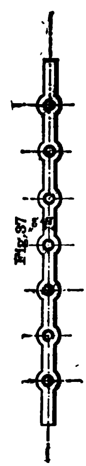


Fig.37

cramped, they fill up rapidly with deposits from the feed-water, and being difficult to clean out, the circulation is greatly impeded, and overheating and fracturing of the plates are very liable to occur. When the length of a firebox is considerably in excess of its width, girder stays, to avoid great depth, should be fitted in the direction of the width, the strength of the girder being inversely as its length. In ordinary practice, however, the difference between the length and breadth of a firebox is not great, and, as a rule, the girders are fitted so as to extend in a longitudinal direction. This arrangement, owing to the formation of the front and back end plates, is better adapted for fitting the girders, and at the same time more suitable for the removal of incrustation from the crown plates.

The total load due to the pressure per square inch on the surface of a crown plate is transmitted by the girders to those parts of the vertical plates on which they rest; and in order to prevent the crushing strength of the material being seriously affected, it is necessary that the extent of the girder bearing-surface should be proportioned with due regard to the strength of the material and the load to be sustained. Instances of tube holes being distorted, and other indications of the crushing limit of the material of fireboxes being attained, are of frequent occurrence; and although such results may be largely caused by deterioration from overheating and other weakening influences, they point to the necessity for a large margin of safety. By increasing the number of girders the load would be distributed over a greater surface, and the stresses on the parts of the vertical plates engaged would be proportionately reduced; but considerations for transmission of heat from the crown plates limit the number of girders that may be fitted, and, as a rule, the distance between, or pitch of the girders, is rarely under 4 inches.

Sling stays extending between the roof of the outer casing and girders are frequently applied to relieve the severe strains thrown upon the plates on which the girders rest, and these when properly arranged assist materially in maintaining the durability of the tube and end plates. The stays for this purpose are made of different sections, and are attached to casing plates and girders in a variety of ways. It is, however, important that provision should be made in every case for the upward expansion of the firebox, which is at all times greater than that of the outer casing, but particularly so when fires are just kindled.

The obstruction which girder stays present to the ascent of heat from the crown plate, and their tendency to collect deposit at a part where its presence is liable to be injurious, are the principal objections to their use. At the same time, it should be stated that the crown plate is rarely the first part of the firebox or boiler which gives way, for on referring to the records of locomotive boiler accidents, it will be found that whilst many have been due to failure of the side and end plates of fireboxes, and to fracture or grooving of the outer casing and barrel plates, very few have been caused in consequence of the crown plates being impaired by disadvantages attending the use of girder stays. The mud plug-openings, usually made in the front plates of outer casings, give fair access for cleansing rods, and with ordinary attention there should be little difficulty in preventing anything approaching to a serious accumulation of deposit on the crown plates.

The girder, as applied to firebox crown plates, is usually treated as if it were an ordinary beam, having both ends supported, but not fixed, over the length of which the load is uniformly distributed. The strength imparted to the girder by its attachment to the crown plate is a matter which has not been satisfactorily determined; and with the

exception that some makers adopt girders, having otherwise a low factor of safety, it is disregarded in the rules for determining the safe load.

There are various formulæ by which the number and proportions of girder stays may be determined, but they are for the most part stated in such a manner as to be of little service to many of those interested in the construction and safety of steam boilers. With a view to simplifying these, the following rules have been deduced, and they may be relied upon to give results that will compare favourably with the best practice.

Referring to Figs. 36, 37, 38, and 39 it will be seen that the letters used to denote the various dimensions are as here given:—Let

P = Working pressure in lbs. per square inch.
L = Length of girder in inches = length of firebox.
H = Half length „ „
B = Breadth of girder in inches, or if formed of two plates, take the sum of the two.
D = Depth of girder in inches at centre.
S = Distance between centres of girders.
C = Constant, 7,500 for iron, and 10,000 for steel.

Then $$P = \frac{C \times B \times D^2}{H \times L \times S} \qquad D = \sqrt{\frac{H \times L \times S \times P}{C \times B}}$$

and B = one-fourth to one-fifth of the depth.

The diameters and pitch of the bolts which transmit the load to the girders are determined by the rules already given for screwed stays.

Taking the dimensions as given, and using constant for iron—

$$P = \frac{7{,}500 \times 2 \times 50}{25 \times 50 \times 4} = 147 \text{ lbs. per square inch.}$$

$$D = \sqrt{\frac{25 \times 50 \times 4 \times 147}{7{,}500 \times 2}} = 7 \text{ inches for iron.}$$

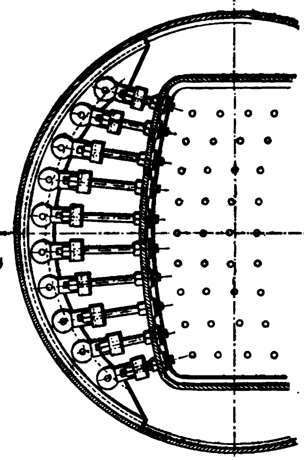


Fig. 41

Section through line A B

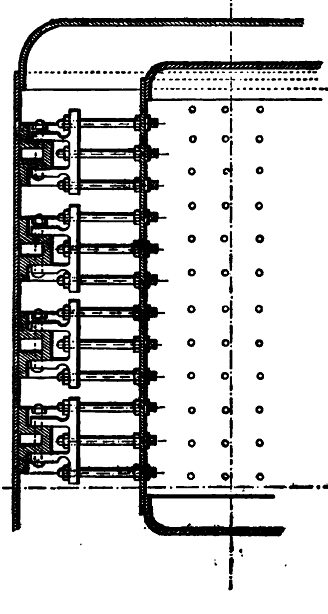


Fig. 40

Section through line C' D

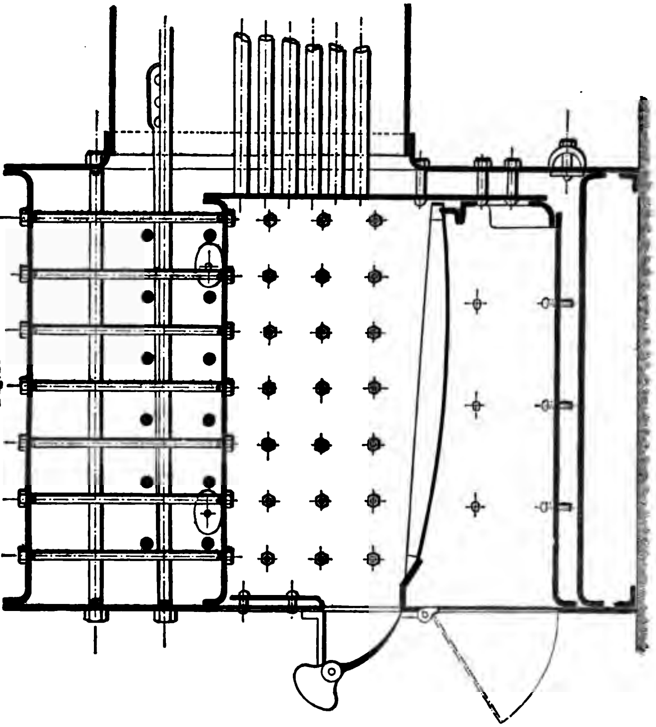


Fig.43

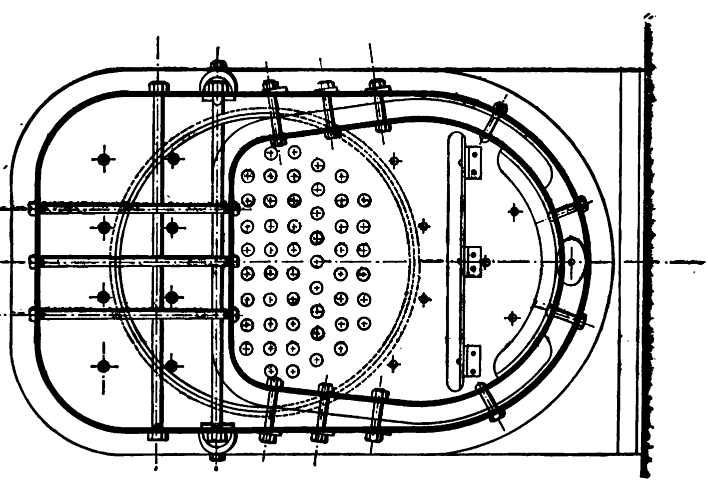


Fig.42

The disadvantages referred to as attending the use of girder stays, have induced several locomotive builders to adopt a mode of staying between the crown plates of firebox and outer casing, somewhat similar to that employed in staying the flat sides and end plates. In some instances bolt stays have been screwed through both plates with the heads at firebox side, the ends through casing being fitted with nuts or rivetted over. With casing crown plates, however, of the usual circular form, this method of staying is very rigid, and offers great resistance to the expansion of the firebox; it is also defective, inasmuch as the stays do not take the loads direct, and are thus exposed to bending stresses which must lead to rapid wear and tear. Figs. 40 and 41 show a modification of this form of staying, designed to overcome these objections. A series of channel irons are rivetted to the casing roof, and to these swing brackets suitable for receiving the stay bolts are jointed. The stays are screwed through the firebox plate in the usual manner, and the ends through the brackets are fitted with nuts. Provision is made for the upward expansion of the firebox, and the stays are admirably adapted for supporting the crown plate under pressure; the slight deflection that will occur owing to the difference of expansion between the firebox and the casing being immaterial. The casing roof is doubtless very much stiffened by the channel irons to which the stays are attached, and the altered conditions may in time develop "wear and tear" at parts hitherto comparatively free from it. The first cost and the difficulty of renewing or repairing the stays are also points which require consideration, but the improved circulation and facilities for cleaning which the arrangement possesses over girder staying will probably make its adoption very general, particularly in the case of large boilers.

Figs. 42 and 43 represent a mode of constructing locomotive fireboxes, which admits of crown plates being stayed directly to outer casing without disadvantage. It will be seen that the crown plates of both outer and inner boxes are quite flat and of about equal area; the side plates of casing being connected to the roof by bends of large radii. Unequal expansion between the boxes is accommodated by the springing of the plates in such a manner as to prevent serious straining. The easy bends at corners of casing will also be serviceable in this respect, and under ordinarily favourable conditions they are not likely to be affected by grooving. This design for the many small boilers of "loco" type possesses great advantage over girder staying, particularly when the feed-water is bad; it is also much simpler and less expensive than other good forms of direct staying.

(4.) BURSTING PRESSURES OF CYLINDRICAL BOILERS.

The cylindrical, next to the spherical, is the form that offers the greatest resistance to rupture, and as cylindrical boilers are not only simpler to construct, but are better adapted in other respects to suit the requirements of steam generators, this form has naturally been most generally adopted.

The resistance of a cylindrical shell to rupture is equal to the tensile strength of the material multiplied by twice its thickness, and the force sufficient to overcome the resistance is the product of the pressure in pounds per square inch multiplied by the diameter in inches. Thus, a boiler 60 inches in diameter, constructed of plates $\frac{3}{8}$ inch thick, having a tensile strength of 40,000 pounds per square inch of

section, would resist rupture up to a pressure of 500 lbs. per square inch.

$$\frac{\frac{3}{8} \times 2 \times 40{,}000}{60} = 500$$

The strength of solid plates has here been taken, but as the rings of plating which go to form the shell of a boiler are made up of one or more plates, which are jointed and held together by rivets, a reduction equal at least to the section removed for rivet holes requires to be made. The ordinary forms of rivetted joints are single and double laps, and the values of these joints are usually taken at 56 and 70 per cent. of the strength of the solid plate. The bursting pressure of a boiler of the dimensions given above would therefore be $500 \times \cdot 56 = 280$ lbs. per square inch for single rivetting, and $500 \times \cdot 7 = 350$ lbs. per square inch for double rivetting. The increased rivet area in the double-rivetted joint admits of wider pitches being employed, and the plate section thus saved accounts for the increase of strength that double-rivetted have over single-rivetted joints. Many joints are found which if measured by the amount of rivet area would show a strength in excess of the solid plate, whereas their actual strength measured from the plate section left between the rivet holes, might not exceed 40 per cent. of the solid plate. And as the weakest link in a chain is the measure of its strength, so the weakest section (rivet or plate as it may be) of a rivetted joint is that which determines the ultimate strength of the boiler. The tensile strength of iron plates is slightly greater than the shearing strength of rivet iron, but the former being more liable to injury under manipulation, as well as from the action of corrosive agencies in the feed-water, it is customary to proportion rivetted joints as if the plates and rivets presented equal resistance to the respective strains.

The correct proportions, from a theoretical point of view

would therefore be those that arranged for the plate and rivet sections of an iron joint being equal, and these conditions will be obtained when the pitch of rivets is equal to $\frac{a \times n}{t} + d$, where a is area of one rivet, n = number of rows of rivets in the joint, d = the diameter of rivets, and t = thickness of plate. There are several considerations, however, which render an excess of rivet section over plate section desirable, and this is generally carried out in practice. A rivetted joint besides being strong must be steam and water tight, and by increasing the rivet area the plates are held more firmly together, and being better adapted for caulking are less liable to leakage.

When steel is employed, it is necessary that the difference between the tensile and shearing strengths should be taken into account in the proportions of the joints. Steel boiler plates as commonly specified have a tensile strength ranging from 26 to 30 tons, or an average of 28 tons per square inch, whereas the shearing strength of good rivet steel rarely exceeds 23 tons per square inch of section.

(5.) STRENGTH OF RIVETTED JOINTS (IRON).

The percentage of strength due to the plate section left between the rivet holes is computed by the formula—$\frac{P - d}{P} \times 100$, where P is equal to pitch, and d = the diameter of rivets.

The strength of the rivet section is computed by the formula $\frac{a \times n}{P \times t} \times 100$, where a is the area of one rivet, n = the number of rows of rivets, P = the pitch, and t = the thickness of plate.

Example 1.—Find the strength of a single-rivetted lap-joint where $P = 1\frac{7}{8}$ inch, $d = \frac{3}{4}$ inch, and $t = \frac{3}{8}$ inch; then,

$$\frac{P - d}{P} \times 100 = \frac{1{\cdot}875 - {\cdot}75}{1{\cdot}875} \times 100 = 60 = \text{percentage}$$

of strength of plate section to solid plate,

and

$$\frac{n \times a}{P \times t} \times 100 = \frac{1 \times {\cdot}4417}{1{\cdot}875 \times {\cdot}375} \times 100 = 62{\cdot}75 = \text{percentage}$$

of strength of rivet section to solid plate.

Example 2.—Find the strength of a double-rivetted lap-joint where $P = 2\frac{3}{4}$ inch, $d = \frac{13}{16}$ inch, and $t = \frac{1}{2}$ inch; then,

$$\frac{P - d}{P} \times 100 = \frac{2{\cdot}75 - {\cdot}8125}{2{\cdot}75} \times 100 = 70{\cdot}5 = \text{percentage}$$

of strength of plate section to solid plate,

and

$$\frac{n \times a}{P \times t} \times 100 = \frac{2 \times {\cdot}5185}{2{\cdot}75 \times {\cdot}5} \times 100 = 75{\cdot}5 = \text{percentage}$$

of strength of rivet section to solid plate.

The percentages of plate section in the examples given, being less than the rivet area, are the quantities that would be taken in calculating the bursting pressure of boilers rivetted together by joints of these proportions, and for the same reason, when the percentage of plate section is the greater, the strength due to the rivet area must be taken.

The proportions given in the following tables are very commonly used in good modern practice, experience having proved that rivetted joints formed in accordance with these can be made thoroughly reliable. It will be seen that several of the rivet diameters in Table I. are greater than those given for the same thickness of plate in Table II. The former table applies only to boilers having both longitudinal and circular seams single rivetted. In those boilers

where the longitudinal seams are double and the circular seams are single rivetted, the diameter of rivet which is best adapted for the longitudinal joint must also—for convenience in construction—be taken for the circular seams, the pitch of the latter being increased or decreased, as found necessary to obtain the highest efficiency.

TABLE I.—SINGLE-RIVETTED JOINT (IRON).					TABLE II.—DOUBLE-RIVETTED JOINT (IRON).				
Thickness of Plate.	Diameter of Rivet-Hole.	Pitch of Rivets.	Percentage of Plate Section to Solid Plate.	Percentage of Rivet Section to Solid Plate.	Thickness of Plate.	Diameter of Rivet-Hole.	Pitch of Rivets.	Percentage of Plate Section to Solid Plate.	Percentage of Rivet Section to Solid Plate.
Inch.	Inch.	Inch.	Per Cent.	Per Cent.	Inch.	Inch.	Inch.	Per Cent.	Per Cent.
$\frac{1}{4}$	$\frac{1}{2}$	$1\frac{1}{4}$	60	63	$\frac{1}{4}$	$\frac{1}{2}$	2	75	$78\frac{1}{2}$
$\frac{5}{16}$	$\frac{5}{8}$	$1\frac{9}{16}$	60	63	$\frac{5}{16}$	$\frac{5}{8}$	$2\frac{3}{8}$	$73\frac{3}{4}$	$82\frac{3}{4}$
$\frac{3}{8}$	$\frac{3}{4}$	$1\frac{7}{8}$	60	$62\frac{3}{4}$	$\frac{3}{8}$	$\frac{11}{16}$	$2\frac{1}{2}$	$72\frac{1}{8}$	79
$\frac{7}{16}$	$\frac{13}{16}$	$1\frac{7}{8}$	$56\frac{1}{2}$	63	$\frac{7}{16}$	$\frac{3}{4}$	$2\frac{5}{8}$	$71\frac{1}{8}$	77
$\frac{1}{2}$	$\frac{7}{8}$	2	$56\frac{1}{4}$	60	$\frac{1}{2}$	$\frac{13}{16}$	$2\frac{3}{4}$	$70\frac{1}{2}$	$75\frac{1}{2}$
$\frac{9}{16}$	$\frac{15}{16}$	$2\frac{1}{8}$	56	$57\frac{3}{4}$	$\frac{9}{16}$	$\frac{7}{8}$	$2\frac{15}{16}$	$70\frac{1}{4}$	$72\frac{3}{4}$
$\frac{5}{8}$	1	$2\frac{1}{4}$	$55\frac{1}{8}$	56	$\frac{5}{8}$	1	$3\frac{3}{8}$	$70\frac{1}{4}$	$74\frac{1}{8}$

The tensile strength of steel plates being 28 tons, and the shearing strength of steel rivets being 23 tons per square inch, the rivet area must be increased proportionately to obtain the same value in strength, as given in the examples of iron plates and rivets. By Example 1 it was found that the percentages of strength of plate and rivet section were respectively 60 and $62\frac{3}{4}$. The same percentages would be obtained in the case of steel plates and rivets by the calculation, but the *value* of the rivet to the plate section would be in the proportion of 23 to 28, and instead of it being equal to $62\frac{3}{4}$ per cent. of the solid plate, as with iron, it

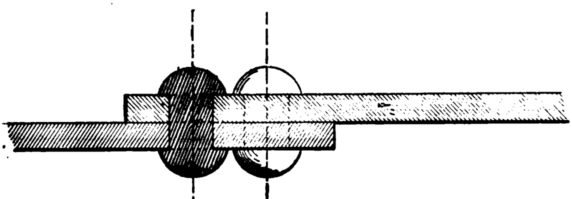


Fig. 44

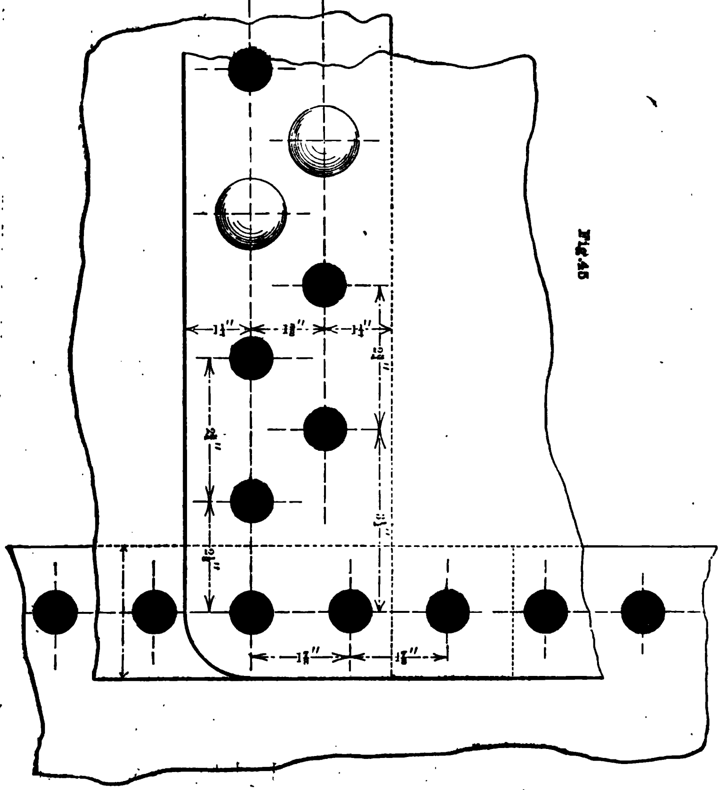


Fig. 45

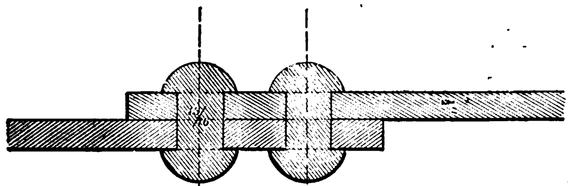


Fig. 46

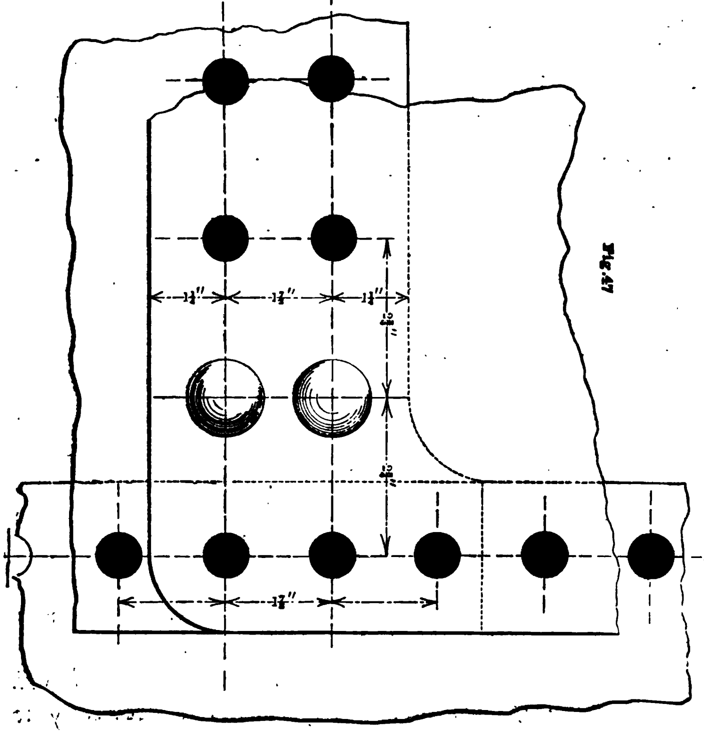


Fig. 47

would only be equal to 51½ per cent.; thus, $\frac{62.75 \times 23}{28} =$ 51·5. In the same manner the value of the rivet section (75½) obtained in Example 2 would only be equal to 62 per cent. of the solid plate—thus, $\frac{75.5 \times 23}{28} = 62$. The plate and rivet sections of an iron joint, as stated elsewhere, will be of equal strength when the pitch is found by the formula, $\frac{a \times n}{t} + d = \mathrm{P}$, but to obtain the same results with steel joints, the formula becomes $\frac{a \times n \times 23}{t \times 28} + d = \mathrm{P}$. With plates ⅜ inch thick, and rivets ¾ inch diameter, the pitch for a double-rivetted steel joint would be $\frac{.4417 \times 2 \times 23}{.375 \times 28}$ $+ .75 = 2.69$ inches, which, by the formula, would give 72 per cent. of plate section, and 87·6 per cent. of rivet section; but $\frac{87.6 \times 23}{28} = 72$, which is the *value* of the shearing strength of the rivets, as compared with the tensile strength of the solid plate.

In double-rivetted joints the arrangement of the rivets may either be "zig-zag" as in Figs. 44 and 45, or "chain" as in Figs. 46 and 47. The former of these methods requires less lap than the latter, and the rivet pressure being consequently greater per square inch of surface, these joints, if well executed in other respects, should be sounder than those which are "chain" rivetted. On the other hand, the material with zig-zag rivetting is more liable to be injured under manipulation, particularly when the rivet holes are punched, and there is always the difficulty of getting the corner rivets to come in without departing from the general proportions of pitch and diameter.

The "zig-zag" arrangement is more frequently employed than the "chain," but further experiment is necessary to

determine which of the two methods is better adapted for equalising the strains and giving the strongest joint.

The other forms of rivetted joints are treble-rivetted laps, and single and double butt joints. The former of these is rarely adopted in land boilers; but in lap-jointed marine and other boilers, where thick plates are used, the rivet area required to bring up the strength of the joint renders treble rivetting necessary.

Butt joints (Figs. 48 and 49) when properly proportioned and carefully executed, are stronger than lap joints; the rivets being in double shear, and as the rings of plating can be made truly cylindrical, they are free from the cross bending strains to which lap joints are subjected. This feature in butt jointing, as elsewhere explained, effectually prevents the grooving so frequently found at the edges of the longitudinal seams of lap-jointed locomotive boilers, and, next to sound welding, makes it the best method of forming the longitudinal joints of furnace tubes. Butt joints are more difficult to make, and being thus more liable to suffer from defective workmanship than the ordinary lap joint, they require to be very carefully supervised during construction.

Butt joints fitted with single straps have little, if any, advantage over lap joints in point of strength, and as it is more difficult to make thoroughly sound work with the former, they are seldom employed in boiler construction.

The circular seams of land boilers, as a rule, are single rivetted, there being no necessity, as will be seen, for double rivetting to enable them to resist with safety the stresses due to internal pressure. The springing at these joints, resulting from the inequalities of temperature found between the top and bottom of certain boilers (mostly of marine type), is frequently the cause of annoying leakages, to prevent which double and occasionally treble rivetting is resorted to, but it is only for such reasons that single

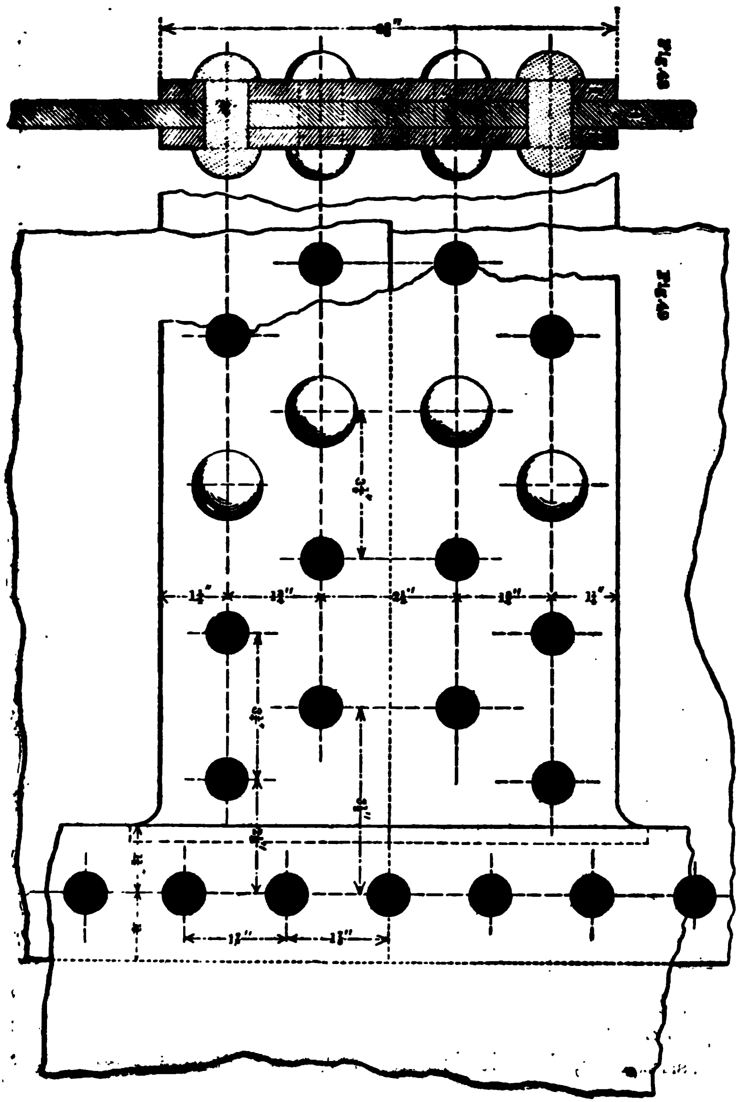


Fig. 48

Fig. 49

rivetting is departed from. The strength at the circular seams of a plain cylindrical boiler to resist tearing asunder by force of internal pressure, is double that of the longitudinal seams, when the proportions of rivetting, &c., are equal, and in boilers which have tubes and stays extending between the end plates, the strains tending to tear asunder the circular seams are still further reduced.

The pressure at which rupture of the circular seams would occur is equal to $\frac{S \times p}{A}$, where S is the sectional area of the plates, p the strength of the joint compared with the strength of the solid plate, and A the area of the end plate in square inches.

The pressure at which rupture of the longitudinal seams would occur is equal to $\frac{t \times 2 \times p}{d}$, where t is the thickness of plate, p the strength of the joint, compared with the strength of the solid plate, and d the diameter of boiler in inches.

Example.—What are the pressures required to produce rupture through the circular seams and longitudinal seams of a boiler 5 feet (internal) diameter, composed of plates $\frac{3}{8}$ inch thick, the tensile strength of which is 40,000 lbs. per square inch, and the efficiency of the joints (single-rivetted) 56 per cent. of the solid plate? S, The sectional area of the plate is the difference between the area of the outer and inner circles of the boiler, which in this case are 5 feet $\frac{3}{4}$ inch, and 5 feet respectively; thus, $2898{\cdot}5 - 2827{\cdot}4 = 71{\cdot}1$ square inches sectional area. p, The strength at the joint is $\frac{40{,}000 \times 56}{100} = 22{,}400$ lbs. per square inch. A, Area of the end plate 5 feet diameter $= 2827{\cdot}4$ square inches. Then, $\frac{S \times p}{A} = \frac{71{\cdot}1 \times 22{,}400}{2827{\cdot}4} = 563$ lbs., the pressure that

would produce rupture through circular seams. And, $\frac{t \times 2 \times p}{d} = \frac{\cdot 375 \times 2 \times 22{,}400}{60} = 280$ lbs., the pressure that would produce rupture through the longitudinal seams.

In this example the full area of the end plate has been taken, whereas in multitubular and internally-fired boilers the area of the tubes and flues would require to be deducted, and the pressure necessary to produce rupture at the circular seams would be proportionately greater.

The strength of the circular seams, as compared with the longitudinal seams, shows the necessity for double rivetting, or other improved form of jointing the latter; for with an efficiency of 80 per cent. at the joint, the bursting pressure of 280 lbs. found in the above example would be increased to 400 lbs., and the chances of leakage under working conditions would be very much reduced.

TABLE OF AREAS FROM 30 INS. TO 108 INS. DIAMETER.

Dia. in Ins.	Area in Square Inches.	Dia. in Ins.	Area in Square Inches.	Dia. in Ins.	Area in Square Inches.	Dia. in Ins.	Area in Square Inches.	Dia. in Ins.	Area in Square Inches.	Dia. in Ins.	Area in Square Inches.
30	706·8	45	1590·4	60	2827·4	75	4417·9	90	6361·7	105	8659·0
33	855·3	48	1809·6	63	3117·3	78	4778·4	93	6792·9	108	9160·9
36	1017·9	51	2042·8	66	3421·2	81	5153·0	96	7238·2	...	...
39	1194·6	54	2290·2	69	3739·3	84	5541·8	99	7697·7	...	...
42	1385·4	57	2551·8	72	4071·5	87	5914·7	102	8171·3	...	...

The following table has been computed by the formula, $P = \frac{t \times 2 \times c}{D}$, where P is pressure; t, thickness; D, diameter of boiler; and c, the strength of longitudinal joints—viz., 22,400 lbs. for single and 28,000 lbs. per square inch for double rivetting, the percentages taken being 56 and 70

respectively, and assuming the strength of the solid plate to be 40,000 lbs. per square inch :—

Diameter of Shell in Inches.	Bursting Pressure in Lbs. per Square Inch.														Diameter of Shell in Inches.
	Single Rivetting.							Double Rivetting.							
	$\frac{1}{4}''$	$\frac{5}{16}''$	$\frac{3}{8}''$	$\frac{7}{16}''$	$\frac{1}{2}''$	$\frac{9}{16}''$	$\frac{5}{8}''$	$\frac{1}{4}''$	$\frac{5}{16}''$	$\frac{3}{8}''$	$\frac{7}{16}''$	$\frac{1}{2}''$	$\frac{9}{16}''$	$\frac{5}{8}''$	
30	373	467	560	653	747	840	933	467	583	700	817	933	1050	1167	30
33	339	424	509	594	679	764	848	424	530	636	742	848	954	1061	33
36	311	389	467	544	622	700	778	389	486	583	680	778	875	972	36
39	287	359	431	502	574	646	718	359	449	538	628	718	808	897	39
42	267	333	400	467	533	600	667	333	417	500	583	667	750	833	42
45	249	311	373	435	498	560	622	311	389	467	544	622	700	778	45
48	233	292	350	408	467	525	583	292	364	437	510	583	656	729	48
51	220	274	329	384	439	494	549	274	343	412	480	549	618	686	51
54	207	259	311	363	415	467	518	259	324	389	454	518	583	648	54
57	196	246	295	344	393	442	491	246	307	368	430	491	553	614	57
60	187	233	280	327	373	420	467	233	292	350	408	467	525	583	60
63	178	222	267	311	355	400	444	222	278	333	389	444	500	555	63
66	170	212	254	297	339	382	424	212	265	318	371	424	477	530	66
69	162	203	243	284	324	365	406	203	254	304	355	406	456	507	69
72	155	194	233	272	311	350	389	194	243	292	340	389	437	486	72
75	149	187	224	261	299	336	373	187	233	280	327	373	420	467	75
78	144	179	215	251	287	323	359	179	224	269	314	359	404	449	78
81	138	173	207	242	276	311	346	173	216	259	302	346	389	432	81
84	133	167	200	233	267	300	333	167	208	250	292	333	375	417	84
87	129	161	193	225	257	290	322	161	201	241	282	322	362	402	87
90	124	155	187	218	249	280	311	155	194	233	272	311	350	389	90
93	120	150	181	211	241	271	301	150	188	226	263	301	339	376	93
96	117	146	175	204	233	262	292	146	182	219	255	292	328	364	96
99	113	141	170	198	226	254	282	141	177	212	247	282	318	353	99
102	110	137	165	192	220	247	274	137	171	206	240	274	309	343	102
105	107	133	160	187	213	240	267	133	167	200	233	267	300	333	105
108	104	130	155	181	207	233	259	130	162	194	227	259	292	324	108

(6.) FACTOR OF SAFETY.

The term "Factor of Safety" refers to the proportion of strength which a structure possesses in excess of the load or strains to which it is subjected. For instance, a boiler shell 69 inches diameter, built of $\frac{3}{8}$-inch plates and single rivetted, has an ultimate strength to resist rupture up to a pressure of 240 lbs. per square inch, and if the working load should not exceed a pressure of 40 lbs. per square inch; such a boiler, in the ordinary acceptation, is said to have a factor of safety of 6, thus $\frac{240}{40} = 6$.

This method of estimating the factor of safety of a boiler, although accurate to a certain extent, is very liable to give a false sense of security, and has in not a few instances led to boilers being unduly pressed. In the example given above, the ultimate strength of the material of which the boiler shell is made—viz., 40,000 lbs. per square inch, has been taken, whereas the limit of elasticity of the material would not exceed one-half of this amount. The elastic limit of any material (possessing the quality of elasticity), is that point up to which it will sustain a load without permanent alteration of form. Iron of good quality, as already indicated, has been found to possess elasticity equal to a load of 20,000 lbs. per square inch, that is to say, so long as the strain to which the iron is subjected is within this limit, it will elongate in proportion to the load applied, and after release, it will go back to its original form. On the other hand, should the strain exceed the elastic limit, the original form will not be retained after release of load, and exhaustive experiments have proved that with each increment, or with repeated applications of same load thereafter, the departure from original form will increase rapidly until

final rupture ensues. From what has been said it will be seen that a boiler of the dimensions referred to, would be in a most unsafe condition, if loaded up to anything approaching one-half of its calculated bursting pressure, and it follows that for practical purposes the *limit of elasticity* should be taken instead of the ultimate strength of the material, which reduces the nominal factor of safety of 6 to an actual factor of safety of 3.

The soundness of the rivetted joints (as is well known to those who have witnessed the testing of boilers to destruction) is also a point that would be seriously affected long before the actual strength of the plate and rivet section would be reached; and although such a result might not be followed by immediate disaster, it would rapidly affect the durability and efficiency of a boiler.

Besides the reasons given in the foregoing for a large nominal factor of safety in respect of the steam pressure, a margin is also necessary for probable flaws in material, defects in workmanship, and for the undetermined stresses to which most boilers are subjected whilst under working conditions.

The improvements in the construction and setting of boilers introduced during recent years have doubtless assisted considerably in minimising the stresses due to unequal expansion, and otherwise reducing the influences tending to cause rapid deterioration; but the best results are still far short of perfection, and it is impossible to get over the fact that every day's work detracts, in some measure, from the original strength of the structure.

The degree of accuracy with which the strength and elasticity of boiler materials can be ascertained, and the facilities for high-class construction that are now in use, have removed to a great extent the uncertainty that formerly existed as to the actual strength of new boilers,

and the rules generally applied are sufficiently reliable for all practical purposes. To estimate the strength of a boiler which has been at work for a term of years is, however, a matter to which the recognised rules can only be applied with such modifications as sound practical experience may determine.

With good feed-water and careful working, boilers have been known to last for upwards of 20 years without material reduction of plate thickness, or other outward indications of decay; but even under such favourable circumstances, experience has proved that the high temperatures and varying conditions to which the plates are exposed, detract materially from their original strength and elasticity. The majority of boilers, in addition to the species of deterioration just referred to, are also affected by corrosion, fractures, and repairs, &c., sometimes to such an extent as to make it almost impossible to estimate their fitness for pressure, and these difficulties are increased when the construction of boilers is such as to prevent a complete examination being made of every part.

The testing of boilers by hydraulic pressure, the drilling of plates to ascertain their actual thickness, and the testing of pieces cut out during repairs, are often necessary to enable the expert to apportion a safe load; and in view of the tendency to high working-pressures that is now becoming so general, these precautions will require to be more frequently resorted to. The management and care in the working of boilers are also matters that affect largely any estimate of their fitness for a given pressure, it being well known that irregular working, forced firing, and impure feed-water, &c., are productive of serious straining, and consequent reduction of strength. The length of time a boiler should be allowed to work at the pressure which its dimensions and construction justified when new, is indeed very largely dependent

upon the nature of the feed-water supplied, and the attention that the boiler receives; but under average conditions it may be assumed that after ten years working, more or less, the strength and ductility of the plates will be so affected as to make a reduction of pressure advisable.

The working-pressures specified for new boilers usually vary from one-fifth to one-eighth of the calculating bursting pressure, based on the ultimate strength of the materials, and in no case is it judicious to load the safety-valve in excess of one-fourth of the estimated strength of any boiler. Such a factor of safety was found necessary even for the low pressures of former days; and, having regard to the high pressures now employed, combined with the somewhat severe shocks which boilers are subjected to by the instantaneous cut-off valves so largely used, it is very desirable that higher factors of safety should become the rule.

SPECIFICATION OF A LANCASHIRE BOILER FOR A WORKING-PRESSURE OF 80 LBS. PER SQUARE INCH.

The boiler to be made throughout of best selected mild steel for boilers, the tensile strength of which shall not exceed 30 tons, or be less than 26 tons per square inch.

Shell.—To be 28 feet long by 7 feet 6 inches diameter, measured inside the outer ring of plates, and to be not less than ½ inch thick (20·8 lbs. per square foot). To have 9 belts of plating in its length, and each belt to be made as cylindrical as possible, with lap joints. The longitudinal seams to break joint at least 12 inches, and to be so arranged that when the boiler is seated they shall not come in contact with the brickwork. The longitudinal seams to be double rivetted, and the circumferential seams to be single rivetted, the proportions being as under :—

For longitudinal,		diameter of rivet-holes,		$\frac{13}{16}$	inch.
„	„	pitch	„	$2\frac{3}{4}$	„
„	circumferential,	diameter	„	$\frac{13}{16}$	„
„	„	pitch	„	$1\frac{7}{8}$	„

The edges of all the plates to be planed and soundly caulked inside and outside, and the distance from centre of rivet-holes to edge of plates to be made equal to $\frac{\text{dia.} \times 3}{2}$.

End Plates.—Each end plate to be in one piece, ⅝ inch thick (26 lbs. per square foot). The front end to be attached to shell by a solid welded angle steel ring, 3½ inches × 3½

inches × $\frac{9}{16}$ inches, which shall be fixed externally, the back end plate being flanged to meet the shell. The edges of both plates and angle ring to be neatly turned, and the holes for flues to be cut out by machine.

Stays.—The end plates to be strengthened by means of five gusset plate stays above the flues, and two below the flues, all being secured to shell and ends by double angle steels, and arranged in accordance with sketch herewith. (See figures 24, 25, 26, and 27.)

Flues.—To be 3 feet external diameter, except the two last belts of each, which shall be tapered to 2 feet 6 inches external diameter. To have 9 belts of plating in their length, which shall be formed of single plates $\frac{3}{8}$ inch thick, welded longitudinally, and united to each other by Bolton steel hoops, Adamson's flanged seams, or other approved method of increasing their resistance to collapse (the method favoured by the contractor to be stated in tender). Each flue to be fitted with four of Galloway's cross tubes. The first of these tubes to be placed vertically in the fourth belt of plates, the others to be fitted in consecutive belts towards right and left sides alternately, each being placed at an angle of 30° from the vertical. The flues to be attached to end plates by angle steel rings, $3\frac{1}{2}$ inches × $3\frac{1}{2}$ inches × $\frac{9}{16}$ inch, or by solid flanged steel collars of same thickness.

Rivet-Holes.—All the rivet-holes to be drilled. The drilling, wherever practicable, to be done with the plates, &c., in position, care being taken to remove the "burr" from between the plates. The rivets to be closed by machine wherever practicable.

Flanging and Welding.—These to be done by the special tools and appliances for such purposes; and to prevent injury by local heating it is desirable that the plate corners be thinned by machine.

Brands.—All plates and angle steels to have the brands

distinctly marked thereon, and a certificate of the tests to which the material has been subjected to be furnished.

Test.—The boiler to be tested to 160 lbs. per square inch by water pressure, and to sustain the same to the satisfaction of the inspector appointed for the purpose. The date of make and pressure to which the boiler was tested to be legibly stamped on front end plate.

MOUNTINGS AND FITTINGS.

Steam Stop-Valve.—One steam-chest having gun-metal stop-valve, and seating 6 inches diameter, fitted with regulating spindle, hand wheel, and packing gland complete.

Safety-Valves.—Two dead-weight safety-valves of ample discharging power, one of which shall be a combined high-pressure and low-water safety-valve.

Feed-Valve.—One combined feed-regulating and back-pressure valve, 2½ inches diameter, attached to front end plate, and having an internal pipe, at least 9 feet long, suitably supported and arranged to discharge horizontally about 3 inches above the level of the furnace crowns.

Blow-off.—One 2½-inch asbestos packed blow-off tap entirely of gun-metal, and having the gland constructed so as to prevent the key being removed until the tap has been closed. The bend pipe for connecting blow-off to boiler to be of approved form, and of such length as may be found most suitable for the convenient working of tap.

Water Gauges.—Two asbestos packed glass-tube gauges complete, of approved construction, with large water and steam passages, and jointed to strong brass stools on front end plate.

Steam Gauge.—One 7-inch steam-pressure gauge of best construction graduated to 180 lbs. and fitted with tap and

syphon complete, and to admit of gauge being tested conveniently, the tap must be made suitable for opening to the atmosphere or boiler as required.

Antipriming Pipe.—One perforated cast-iron pipe to be placed horizontally in steam space, and connected to steam stop-valve.

Fusible Plugs.—One fusible plug to be put into the crown plate of each furnace directly above the centre of fire grate.

Man-holes.—One strong steel double-flanged frame, 16 inches diameter, to be secured by double rivetting to top of boiler *outside*, and the edge of shell plate round opening to be further strengthened by a stiffening piece *inside.*

One strong steel ring 15 inches by 12 inches to be rivetted round man-hole opening at bottom of front end plate *inside.*

Suitable man-hole covers, bolts, &c., to be provided.

Branches.—Steel branches to be rivetted to the boiler for the mountings, and the flanges to which the mountings are to be attached to be accurately faced for jointing.

Fire Doors and Frames.—Two sets of wrought-iron fire doors and frames neatly mounted, the doors to be fitted with air regulating valves.

Fire Bars.—Two sets of fire bars in three lengths of 2 feet 2 inches each (the total length of grate surface being 6 feet 6 inches) with bearers and dead plates.

Damper and Frame.—One damper plate and frame with all necessary fittings.

Flue Doors and Frames.—Two side flue doors and frames of sufficient size for cleaning and inspecting purposes.

Floor Plates and Frame for Blow-off Pit.—The floor plates to be made in sizes to facilitate removal, and to have suitable opening over blow-off tap for inserting spanner. The lid for opening to be fitted flush with plates. The

frame to be of substantial section, and of sufficient size for access to flues.

All Bolts and Jointing necessary for mountings to be supplied by contractor.

Generally the material and workmanship to be of the *best quality*, and the boiler to be constructed and comoleted to the satisfaction of.................

VERTICAL BOILERS.

THE application of steam power to the smaller industries has made great progress of recent years, and owing to this there has been a large demand for boilers of the small self-contained types, amongst which the upright boiler, with internal firebox, is most in favour. Boilers of this class are found, not only to right and left of us, but above, and below, and all around.

In the building of streets, &c., they are used for supplying steam to cranes and mortar mills, and they are also extensively employed by those engaged in the minor industries carried on throughout our large cities and towns. In the loading and discharging of vessels at docks and at seaports, the vertical boiler again plays an important part, both on board ship and on shore, and in all great engineering works, such as railway and canal cuttings and bridge building, they are usually found in large numbers. The first cost of this boiler is low, it is easily moved from place to place, it takes up little space, and it requires no brickwork or other form of special setting. Such qualities render it very suitable and convenient for the various purposes referred to, and, notwithstanding the development of the gas engine and other steamless motors, the demand for the vertical boiler still continues.

In view of this, and having regard to the somewhat numerous accidents which have been recorded, it has been thought advisable, in presenting the second edition of this book, to add a chapter treating of the construction and

management of vertical boilers. Judging from the reviews in several of the scientific journals on the first edition, as well as by the remarks made in a number of letters received, the author has been encouraged to hope that such a chapter will be interesting to many, and it is his earnest desire that it may be of special service to those who are more directly concerned in the safe working of such boilers.

CONSTRUCTION.

There are, perhaps, no boilers which have suffered more from the effects of mal-construction and bad workmanship than the type under consideration. The ease with which they can be manipulated, even in workshops destitute of cranes, as well as many of the most ordinary appliances, has enabled jobbing boilersmiths to compete for such orders, with the result that the design, material, and workmanship have in numerous instances been of the worst possible description. The rapid "wear and tear," and the necessity for frequent repairs, as well as the explosions and collapses which so frequently occur, are doubtless due in some measure to such circumstances; for, whilst it is true that there are conditions incidental to the working of these boilers that render them very liable to failure, it has also been abundantly proved that with good material and workmanship, and due regard to design, they can be made to work, not only with perfect safety, but also with a fair degree of economy. The vertical boiler, like other well-known types, has many modifications, but the prevailing design, viz., that which consists of a cylindrical shell, fitted with an internal firebox, and having an uptake- or chimney-tube extending between the shell and firebox crown plates, is the one to which the following remarks more particularly refer. The departures from this original design consist for

the most part in the introduction of tubular arrangements, which, however beneficial and economical under favourable conditions of water and attendance, render them very unsuitable for many of the purposes to which vertical boilers are applied.

Vertical boilers of the multitubular class, particularly those constructed by leading specialists, have attained to a high degree of evaporative efficiency, and their evaporative duty also compares favourably with that of other good types. Such boilers are very suitable in circumstances where it is necessary to have the greatest possible amount of heating surface in a limited space, and when supplied with good feed-water, combined with careful attention, they have been found to work very satisfactorily. These advantages of increased power and efficiency are, however, obtained at a sacrifice of simplicity in construction, which, besides adding materially to the first cost, is very liable to increase the subsequent expense of maintenance; the operations of cleaning, inspecting, and repairing are also rendered more difficult, all of which objections tend to prevent the vertical multitubular boiler from coming into anything like general use.

SHELL.—The strength of the shell does not call for special remark, beyond what has already been written under the heading of "Cylindrical Boilers." The bursting pressures and rules for the rivetted joints of iron boilers will be found on pp. 81 to 93, and tables for the bursting pressures and strength of rivetted joints of steel boilers on pp. 142 and 143.

It may be well to point out, that as the shells are for the most part of small diameter, it is important that they should be made as truly cylindrical as practicable, particularly for high pressures, and to this end it is desirable that the vertical seams should be formed of double strapped butts, having two rows of rivets on each side of the joints. By adopting

this method, the strength of the shell to resist rupture is considerably increased, and internal grooving, such as is liable to occur, with lap-jointed seams, is entirely obviated. The practice of welding the plates at the vertical joints is a form of construction that cannot be recommended; the uncertainty of soundness at the weld, however carefully executed, is always a grave source of danger, owing to the joint being in tension whilst under pressure, and for this reason it is not uncommon to find welded seams strapped and rivetted, which, of course, adds to the expense of construction, and in the end is no stronger than a rivetted joint. The welding of the crown plates to the cylindrical portions, a method sometimes adopted in the case of small boilers, is also unreliable, and has frequently been the cause of serious failure.

The shell rings should each be formed of a single plate, and preferably of moderate breadth, as undue length of vertical seam is liable to give trouble through leakage. The bottom ring of plating is usually made from 8 inches to 12 inches broader than the others, so as to provide the required space for ashpit, and to admit of easy access to the interior of firebox; this is a more satisfactory method than the rivetting on of a narrow strip, or forming the ashpit of brickwork. The shell crown in good practice is invariably formed of a single plate, having flanges of easy radius for attachment to sides and uptake-tube. The shape of the crown plate is a point about which there is some difference of opinion, certain makers preferring to keep it quite flat, whilst others dish it outwards so as to form a portion of a sphere, the radius of which is usually about equal to the diameter of the shell. The flat plate, it is contended, by reason of its greater elasticity, prevents the tendency to grooving, so common round the roots of shell and uptake-tube attachments; but, except in boilers of small diameters,

and for moderate pressures, flat plates require to be more strongly stayed than those that are cambered. This seriously hampers an already confined space, and tends to stiffen the crown to such an extent as to render its flatness of little service as a means of preventing grooving.

The expense of producing cambered plates was doubtless, at one time, a cogent reason for objecting to their use. The undue stresses to which the material was subjected during manipulation were also liable to cause serious injury, particularly with iron of inferior quality, and this accounts largely for the frequency of fracture and serious grooving round the roots of the crown-plate flanges of many old boilers of this type. The special appliances now employed for the flanging and shaping of boiler plates, besides reducing the cost of production, minimise the chances of injury during manipulation, and concurrent with these improvements, the use of cambered plates has become almost general. Several builders, with a view to dispensing with the necessity for stays, make the crowns hemispherical, but this form of construction adds materially to the height without proportionately increasing the capacity of the boiler, and, except for small diameters, the ends require to be formed of a number of segmental plates, which introduce elements of weakness, and render these ends unsuitable for the attachment of mountings, and uptake-tubes, &c. When the radius of the crown plate is made equal to the shell-diameter, it forms a portion of a sphere, which, if completed, would theoretically sustain an ultimate stress equal to that of the shell. The Board of Trade insist upon all dished ends being furnished with unsmithed bar-stays; but if their radius, as already explained, is equal to the diameter of the shell, the working stress per square inch of stay section may be as high as 14,000 lbs. for iron and 18,000 lbs. for steel stays.

The fitting of bar-stays between the shell and firebox

crown plates is sometimes objected to on the ground that they are difficult to keep tight, and when fitted with nuts and washers, the ends next the fire are very liable to be impaired by the action of the heated gases. For these reasons gusset-stays are sometimes preferred, and in many instances stays are entirely dispensed with, notwithstanding that the dimensions of the boilers, and the pressures to which they are loaded, are such as to render some form of staying extremely desirable if not absolutely necessary. Gusset-stays between the shell and crown plate are, doubtless, a very effective means of support, but when it is necessary to apply these, it is equally important that the firebox crown should be stayed, for, although the latter is usually from 20 to 30 per cent. less in area, it is in compression whilst under pressure, and the working stress on the material should, therefore, be from 20 to 30 per cent. under that allowable on the crown of shell.

In the circumstances it will be seen that, notwithstanding the objections alluded to, the fitting of direct stays is perhaps the best, if not the only, means of effectively supporting both crown plates, and as a means of preventing leakage, the stays, in addition to the usual nut and washer attachments, should be screwed through both plates. The value of the uptake-tube as a stay between the crown plates depends to no small extent upon the conditions of working. If the portion in steam space is unprotected from the direct action of the furnace gases, it is very liable to be softened by overheating, and thereby rendered of little service as a stay; but if provided with a suitable fire-clay or cast-iron lining, and not unduly strained by rapid and extreme variations of temperature and pressure, its staying properties must be of considerable importance. This is borne out by the comparative freedom from accident through failure of uptake-tubes in boilers, the crown plates

of which were otherwise unsupported. It is true that there are no stays which are more exposed to the weakening effects of grooving, corrosion, and overheating, but, notwithstanding these drawbacks, the uptake-tube may with ordinary care last the lifetime of a boiler, and even should it become seriously impaired, its replacement, if properly fitted to begin with, is neither a difficult nor an expensive affair.

Whilst admitting to this extent the reliability and probable durability of the uptake-tube, it must also be stated that amongst the makers and users of vertical boilers, there are not a few who rely too implicitly on the understanding that by its staying power alone, the crown plate possesses a margin of safety against rupture equal to that of the shell. It would also appear as if this view of the matter were at times adopted without regard to the necessity for the sectional area of the uptake-tube being made proportionate to the pressure to be sustained. The dimensions, mode of attachment, and design vary to a great extent; boilers are found fitted with tubes absurdly large or absurdly small, and not infrequently those of greatest diameter are too thin to have even a fair margin of safety against collapse. If the uptake-tube is to be considered as a stay in any degree whatever, its efficiency must of necessity be greatly affected by its diameter and thickness, whereas judging from some of the instances referred to, these would appear to be of no moment. The great increase of working pressure to which vertical boilers, in common with other types, are now subjected, renders such haphazard methods of construction dangerous in the extreme, and it points to the necessity for some law being framed, whereby all makers would be bound to submit drawings and specifications of every boiler to some qualified and responsible authority. The Board of Trade rules do

not refer to the uptake-tube as a stay, but they allow a large working stress on direct stays between the crowns when the latter are properly cambered, and it is at least presumable that the strength imparted by the uptake-tube accounts for this to some extent. It is perhaps quite right to lay down as a general rule that "all dished end plates should be stayed;" but there are many vertical boilers in which the insertion of stays, other than the uptake, is quite unnecessary, and as their presence would probably add to the chances of leakage, not to speak of other forms of deterioration, it is evident that some other understanding beyond the general rule just referred to is required. To lay down any hard and fast rule on the point would simply be adding to the difficulties already experienced, but the following statements and particulars of the author's practice in reference to the staying of crown plates may be found of service, and as the proportions given have been proved by the test of actual working over a wide range, they may be relied upon to meet the requirements of what might be termed average conditions of working.

Proportions of Uptake-Tubes and Crown Plates of Vertical Boilers, from 3 ft. to 6 ft. diameter.—The radius of the crown plates should be equal to the diameter of the shell, the thickness after dishing and flanging being at least 20 per cent. greater than the shell plates, and the radius of the crown-plate flanges should be not less than 2½ inches. The mode of attaching the uptake-tube may be varied to suit circumstances, but the practice of flanging the crown plates for this purpose is the most approved, and when adopted, the tube might be made slightly conical, so as to facilitate its removal, when required, for repairs. Long tubes of large diameter may with advantage be made in two lengths, united to each other by flanged seams, care being taken to keep such seams

below the water line. The diameter of the uptake-tube should be made to allow of a protecting liner or sleeve being fitted at the fire-side, without unduly contracting the outlet area, and the sectional area of the material of the tube should be so proportioned as to make it effective as a stay between the crowns. The liners for protecting the steam-space portions of the uptake-tubes may be made of fire-clay or cast iron. The former lasts very well in boilers which are free from jolting, but cast-iron liners will be found more serviceable for boilers on cranes and steamboats, &c., and to prevent corrosion it is important that an air-space $\frac{3}{4}$ inch in width be left between tubes and liners.

For working pressures in excess of those given in the following Table, the crowns should be supported by means of unsmithed bar-stays, screwed through both plates and fitted with nuts and washers at each side of each plate. To prevent these stays from unduly obstructing the man-hole access, they require to be rather widely spaced; but except for extreme pressures, pitches varying from 20 inches to 25 inches (measured on the pitch line of shell crown plate) will be found quite suitable for the sizes of boilers given in the Table. The centre of the space on the crown plate between the shell and uptake-tube is usually fixed upon as the pitch circle of the rod-stays; it has, however, been found advantageous to leave a larger breathing space round the uptake-tube than this allows, and, as a general rule, the diameter of the pitch circle should be made not less than two-thirds of the diameter of the shell. If the stay-holes have been truly drilled and tapped in line with each other, and the stays have been manufactured and fitted as already described, they may be subjected to a working stress not exceeding 20,000 lbs. per square inch of net section for steel, and 15,000 lbs. per square inch for iron.

TABLE OF PROPORTIONS OF UPTAKE-TUBES AND MAXIMUM WORKING PRESSURES.

Diameter of Shell.	External Diameter of Uptake-Tube.	Minimum Thickness of Uptake-Tube.	Maximum Working Pressure Without Stays.
3 feet 0 inches.	10½ inches.	$\frac{3}{8}$ inch.	80 lbs. per sq. in.
3 ,, 6 ,,	12 ,,	$\frac{13}{32}$,,	75 ,, ,,
4 ,, 0 ,,	13½ ,,	$\frac{7}{16}$,,	70 ,, ,,
4 ,, 6 ,,	15¼ ,,	$\frac{15}{32}$,,	65 ,, ,,
5 ,, 0 ,,	17 ,,	$\frac{1}{2}$,,	60 ,, ,,
5 ,, 6 ,,	18½ ,,	$\frac{17}{32}$,,	55 ,, ,,
6 ,, 0 ,,	20 ,,	$\frac{9}{16}$,,	50 ,, ,,

Man-holes, Mud-holes, and Fire-hole Openings.—The man-hole, mud-hole, and fire-hole openings into shell are not always fitted to the best advantage, or placed in the most favourable positions for their respective purposes. The man-hole should be cut in the centre of the space, between the crown plates of the shell and firebox, as generally this position is quite suitable for accessibility to the interior of the boiler, and the jointing is wholly in the steam space, a feature which, it may be stated, is of importance, as it has been found more difficult to keep the joint tight when it is partly in the steam- and partly in the water-space. The plate edges round the opening should be strengthened by wrought-iron or steel rings of such proportions as will substantially compensate for the section of shell plate removed. These rings may be made and rivetted, as shown by Figs. 22 and 23 on page 53, and in the case of existing boilers having unstrengthened man-holes, such an arrangement is the most suitable for shells

of average diameter. Great care, however, is required to ensure tightness, owing to the man-hole doors having to be jointed to the curvature of the shell. Flanged compensating rings, fixed internally, are admirably adapted for the strengthening of man-holes, particularly of those in vertical and other boilers, where the space is limited. The faces of these rings and the man-hole lids being flat, they can be accurately machined and scraped up so as to form thoroughly reliable joints. The double-flanged man-hole frame, although a very effective means of strengthening the edges of the plates, and obtaining sound joints, is not at all suitable for vertical boilers on account of the space it takes up, and as such frames are necessarily fixed externally, the bolts for securing the doors must have their pitches and sectional area proportioned, so as to sustain with an ample margin of safety the load on the area exposed to pressure, whereas, with the flanged rings referred to, the steam pressure tends to keep the joints tight, independently of the bolts or studs for securing the doors. The making of the joints is also much more quickly performed when internally fitted flanged rings are employed.

Man-hole covers are usually made of wrought iron or mild steel; but cast-iron and cast-steel covers are not uncommon. They also vary considerably in form, and they are frequently found to be weak for the pressures they have to sustain, besides being awkward to handle and joint. Cast-iron covers and frames are very unreliable, and they should never be used. Cast steel, although more reliable, is not very suitable for the purpose, as the castings are often of a porous nature, and the flanges of frames made of this material, unless carefully bedded to the shell plates, are very liable to be fractured in rivetting. The man-hole doors, known as M'Neil's "patent embossed man-hole doors," have been subjected to an exhaustive series of

tests by the Board of Trade, with the most satisfactory results. These doors are of Siemens' steel, and they can be made to apply to either internally or externally fitted frames; they can also be used for man-holes, in which the faces have to be set to the curvature of the shell, and when the orifices are cut out accurately to the makers' sizes, these doors can be relied upon to retain the jointing material more securely than those of the ordinary type, many of which are badly made and difficult to fit.

The sizes of the man-hole openings into vertical boilers, except when of small diameter, should not be less than 14 inches by 11 inches, the major axis in all cases being placed circumferentially, and in boilers of larger diameter the openings should be made to admit of easy access to the interior of shells. In small boilers of this type, many of which are 2 feet in diameter, man-holes are not permissible, it being a difficult matter to adequately compensate for the proportion of shell plating that would require to be removed, and in such cases it is better to have small openings judiciously arranged in the upper portions of the shell similar to the mud-holes, opposite the cross tubes in fireboxes, and at bottom of water space.

Mud-holes should be fitted with stiffening or compensating rings, as, without such provision, it is impossible to prevent leakage at the joints, and consequent wasting of the plate edges. When practicable, flanged compensating rings, and embossed doors with flat faces should be used; but when space is too limited to permit of this being done, the edges of the openings can be strengthened by flat rings, rivetted externally, the doors being set to suit the curvature of the shell. Boilers of small dimensions are sometimes provided with plug-holes, for cleansing purposes, instead of the usual mud- or hand-openings; the common practice is to tap these holes, and screw the tapered plugs directly into the shell;

this method, however, is very faulty, as the screw-threads in the thin plates are too few to withstand, for any length of time, the strains caused by the tightening up and unscrewing of the plugs, the result being that the holes are rapidly enlarged, and the threads are also liable to be further worn by the action of the cleaning rods. Mud-plug bosses and special mouthpieces can be fitted round the edges of the holes, so as to prevent the wear and tear of the plate edges; but such contrivances are expensive, and more liable to get out of order than the ordinary mud-hole door, which can be modified to suit boilers of the smallest diameter.

In marking off the **fire-door opening** into shell, due regard should be given to the amount of fuel space required above the level of the grates. When this space is too limited the incandescent fuel is brought into contact with the underside of the fire-door seam and the lap of the fire-box plate, and the rivets at that part are thereby subjected to much undue straining. The desire to reserve space for fitting cross tubes into firebox is the principal reason for keeping the fire-holes so near the bottom; but in boilers of average size, the distance between the level of fire-bars and edges of fire-holes should never be less than 10 inches, and in the larger sizes this distance should be proportionately increased. When the ashpit space is of sufficient depth to allow of easy access to the interior of firebox, the fire-hole need not be more than 10 inches by 9 inches, in shells under 4 feet diameter, but in boilers above this size the openings may with advantage be increased to the dimensions of a full sized man-hole.

Fireboxes.—The strength of the fireboxes of vertical boilers, or the resistance they offer to collapsing pressures, is a point that has deservedly received much attention of recent years from many of our leading authorities, and a number of rules have been given for the guidance of steam users and others interested. Unfortunately, however,

several of the conclusions arrived at, and the formulæ deduced, are, to say the least, somewhat conflicting, and in most cases the working out of the rules is a matter beyond the capabilities of the average steam user and boilermaker. The absence of a generally accepted formula for this object is also the cause of not a little concern on the part of professional and manufacturing engineers. In designing a firebox for a given working pressure, it is often necessary, in the first place, to decide as to which of the various rules has to be acted upon. If the boiler is intended for service on a passenger steamboat, there is no difficulty in this respect, as it must be made throughout to the requirements of the Board of Trade, which admit of no modification, and it would doubtless save an amount of trouble if this law were made to include all boilers. The necessity for strict adherence to the Board's Rules, is not, however, generally admitted, with the result that a very large percentage of vertical boilers are still made, the fireboxes of which would not be passed for the working pressures they have to sustain. The carrying out of the requirements of the Board of Trade involves extra expenditure, and this is probably one reason why some steam users, when they have the option, prefer other methods of construction. It is also an important factor amongst competing boilermakers, some of whom, in their anxiety to secure trade, make cheapness in the cost of construction their chief consideration; apart, however, from the question of cost, there are reliable authorities who adopt a lower factor of safety for fireboxes, on the ground that the results of actual tests, combined with their experience in the working of vertical boilers, justify them in doing so. The methods of strengthening fireboxes prescribed by the Rules are also held by many to be objectionable, and under certain conditions of working to be more a source of weakness than a source

of strength. A high factor of safety (by calculation) may be obtained by the fitting of numerous water-space stays between the shell and firebox plates; but if the feed-water contains much solid matter, and the boiler is in other respects subjected to unfavourable conditions, the *actual* factor of safety may be very low. These stays, it is contended, hamper the already confined water spaces, and as they tend to retain the feed-water deposits at parts exposed to the fiercest heat, the furnace plates are apt to be seriously strained and softened by overheating. They also interfere with cleaning operations, and are very liable to be deteriorated by corrosion and the stresses to which they are subjected by the difference of expansion between the firebox and shell. In consequence of these disadvantages, water-space stays, unless carefully watched and tested from time to time, may indirectly detract to a serious extent from the strength of the box, and give a false sense of security. There is, therefore, under certain circumstances, considerable reason on the part of those who object to their use. A clear water space is at all times a point of great importance (but particularly so when the feed-water contains a large percentage of solid matter), and instances are often quoted to prove that such a condition is a greater guarantee of safety and durability than can be obtained by rigid adherence to rules which insist on stays being fitted. A working pressure of one-fifth of the ultimate strength of the firebox by the formula may be considered a very safe limit, but in the event of serious overheating it would not prevent a collapse from occurring, and in this respect a calculated factor of safety of five, offers no greater security against accident than that obtained by a factor of safety of three.

It may be argued, that in a case of over-pressure, through a safety-valve being unduly loaded or becoming

inoperative, the higher margin of safety might prevent explosion, or, rather, make it less probable, but if the higher margin is obtained by complicated construction, which induces rapid wear and tear of important parts, this conclusion is open to question. It should also be observed that whilst working pressures (with a view to meeting all reasonable contingencies) should be kept well within the ultimate strength, it would be absurd to consider the margin of safety as being intended to guard against accident from such abnormal and inexcusable causes, as shortness of water and inoperative safety-valves, &c. Another method of adding to the strength of fireboxes is by means of cross tubes, which may be flanged at the ends, for attachment by rivetting, or they may be welded to the sides of the box. These tubes are sometimes rivetted at the longitudinal seams, but in good practice they are now invariably welded. In either case, the seams or welds should be placed at the upper sides of the tubes, to keep them free from the direct action of the fire, the tubes should also be slightly inclined so as to facilitate the escape of the steam, and when coned tubes are used, the smaller ends should be the lower ones. The value of these cross tubes as aids towards resisting collapse, although very generally admitted amongst engineers, is not acknowledged, or allowed for, in any of the rules or formulæ for calculating collapsing pressures, and in the absence of any fixed data, the designer must consequently be guided by his own experience in determining to what extent a firebox fitted with cross tubes is stronger than one without. The narrow water spaces in vertical boilers do not admit of flanged seams or encircling hoops being used in the construction of fireboxes; the flanges would also act as ledges for deposit, which might cause rapid deterioration, and until steam users will pay for corrugated or ribbed

fireboxes, water-space stays and cross tubes are the only means of strengthening which are practicable.

The objections to the fitting of water-space stays have evidently tended to increase the importance of cross tubes as firebox supports, and whilst there is not any acknowledged basis, a number of makers act, apparently, on the understanding that cross tubes when properly arranged impart a degree of strength equal to that obtained by having one encircling hoop or flanged seam round the spaces between each set of tubes, or, in other words, those who view the support afforded by cross tubes in this light, take the distance from bottom attachments to the centre of the space, between the first set of tubes, as the length of the box in calculating the resistance to collapse. There is no doubt some force in such reasoning, and until the point has been determined by a series of properly conducted tests, it would be unfair to treat this view of the matter as unsound, all the more so seeing that there are numerous instances of fireboxes constructed and loaded in accordance with this practice, which show no indications of being overstrained or unsafe. Arguments against the use of cross tubes are occasionally advanced, and one authority, at least, has drawn attention to the probability of rapid wear and tear, if not serious accident, that might arise from the stresses induced by the unequal expansion of the various tubes. It is, perhaps, reasonable enough to argue that the tubes will expand unequally, and that each tube will also tend to force the box outwards at that part to which it is attached, with the result that a series of twisting and bending stresses will be produced, which in extreme circumstances might cause grooving and fracture at the flanges of the tubes or distortion of the plates.

The disadvantages here referred to do not appear to be of any vital importance, as, from a careful investigation

of the reports of numerous thorough examinations, there is very little to indicate that either fireboxes or tubes are liable to serious injury from these causes; whilst there is sufficient evidence to show that the improved circulation obtained, combined with the effective heating surface presented by cross tubes, adds to the durability and efficiency of vertical boilers to an extent that more than compensates for any disadvantage arising from their use. If the shells are furnished with suitable hand-holes, as they ought to be, opposite each of the cross tubes, there is no difficulty in keeping the tubes clean, and even under unfavourable conditions the cross tubes are not, as a rule, the first parts to cause trouble, while they have frequently been of great service in preventing total collapse in cases of overheating.

In the construction of fireboxes, it is important that they should be made as truly circular in form as is practicable, and as this condition cannot be obtained except by welding or butting the vertical joints, it is now quite common for good makers to adopt one or other of these methods, but particularly the former. The objections to welding the vertical joints of the shells, already alluded to, do not apply in the same degree to the firebox joints, as they are in compression whilst under pressure, and there is consequently much less danger of a deficiency in the weld being the cause of serious accident. At the same time, flaws in the welding of a firebox plate are liable to develop, more particularly if they occur at parts in contact with the incandescent fuel, and although the danger of explosion may not on this account be imminent, such defects cannot be properly repaired, except at considerable expense and trouble. The welding of the vertical joint of a firebox is an operation which can only be successfully performed by men of special training and experience, as, apart from the necessity for solidity at the weld,

the material requires to be treated with the greatest care to prevent excess or reduction of the proper thickness and loss of strength through undue heating, &c. The danger of failure in obtaining these conditions is, of course, greater with long boxes than with short ones, but generally, unless the work is entrusted to capable hands, it is safer to abide by the rivetted seam, with its known weakness, than to adopt the welded joint with its uncertain strength. There are, doubtless, numerous examples of sound welding, notable amongst which are the shells of fire-engine boilers, in which, notwithstanding that the joints are subjected to tensional stress, high pressures are carried with safety. These results are produced by the employment of specially trained men, who are furnished with all suitable appliances, and the manufacturers of such boilers obtain prices very much above the market value of ordinary boiler work. The boilers referred to are also for the most part of very small diameters, and they are invariably under the supervision of skilled mechanics, whose sole business it is to keep them and the engines in a high state of efficiency, and this necessarily places them outside of all comparison with ordinary vertical boilers. It may also be remarked that a weld is less liable to be affected by being in contact with steam or water than, as in the case of a firebox, where it is exposed to the furnace gases. When the water, however, contains corrosive acids they not infrequently act most rapidly along the lines of the welds.

The practice of rivetting the longitudinal joints of the flue tubes of Lancashire and Cornish boilers is now almost entirely discontinued in favour of welding, and from the success that has attended this departure it might be thought that the welding of the fireboxes of vertical boilers would be equally satisfactory. There are several reasons, however, which prevent this, amongst which the following are

worthy of remark:—The rings of plating which go to form the flues of a Lancashire boiler seldom exceed 3 feet in length, and they are effectively supported by solid flanges or Bolton hoops at each end, whereas fireboxes are commonly from 4 feet 6 inches to 6 feet in length, and they require to be made conical, which adds not a little to the chances of imperfect welding. The welded joints in the firebox of the vertical boiler are necessarily in direct contact with the incandescent fuel, whilst the longitudinal joints of the flues of a Lancashire boiler can be kept well under the level of the fires. The large demand for Lancashire boilers, and the prices they command, enable builders to provide special arrangements for heating, welding, and annealing, all of which are so essential to the obtaining of thoroughly reliable work, but very few of the ordinary makers of vertical boilers are in this position, and whilst they may improvise a fairly good arrangement for welding, they very rarely possess suitable furnaces for annealing, which, it need scarcely be added, is a feature of great importance when steel is the material employed. It may be further remarked that the working conditions of Lancashire boilers are greatly superior to those usually met with in the working of vertical boilers. This although probably a good reason for the exercise of special care in the construction of the latter, has also an important bearing on the question of welding *versus* rivetting of the vertical joints.

Some builders make a practice of flanging the bottom of the firebox for attachment to the shell, whilst others provide for the required water space, by inserting a solid foundation ring, which dispenses with the necessity for flanging, and when properly fitted and rivetted forms a substantial connection. Like many other points in boiler construction there is a good deal to be said for and against each method. The flanging of the box outwards, when

performed by means of repeated heating, in a common fire, is liable to injure the material and reduce it in thickness; there is also the danger of the box being knocked out of circular form, and when this occurs, it is very difficult, if at all possible, to restore its shape by the ordinary appliances. These disadvantages are greater or less in proportion to the dimensions of the box, and the care which has been exercised during manipulation, but their effects may be traced in a considerable percentage of the fireboxes so constructed, the excessive grooving and fracturing found at the roots of the flanges being quite as frequently due to such causes as to the wear and tear incidental to the working of the boilers. By means of the flanging machine, now so successfully employed, the danger of the material being injured is almost entirely removed, and firms possessed of such appliances are quite capable of making a satisfactory connection between the firebox and shell. Flanged fireboxes take up more room than those fitted with foundation rings, and where vertical height is limited, this may be of some importance. When properly formed, the flange imparts an amount of elasticity which reduces the stresses on the uptake-tube and crown-plate flanges, and thereby lessens the tendency to grooving from unequal expansion.

Foundation rings are not uncommonly made too shallow, their depth apparently being regulated by the width of the water space, which is frequently too small to allow of the required lap or distance between the edges of the plates and edges of the rivet holes. It may be very convenient to form the rings out of square bars, but to obtain a proportionate lap, even for single rivetting, the ring should not be less than 2½ inches in depth, whatever its width, and in no case should the depth be less than the width. For large boilers, and even for small ones which are subjected to high pressures, the foundation rings should be

double rivetted, the rivet holes being drilled or rymered out perfectly fair in position, and rivetted up by machine. When foundation-ring seams are rivetted by hand, they invariably cause trouble through leakage, owing to the rivets not filling the holes throughout their length, and this is all the more important seeing that there are two distinct seams to be kept tight by the same rivets with this connection, as compared with one when the firebox is flanged to meet the shell.

To sum up the merits and demerits of the two methods for attaching fireboxes to the outer shells:—If the size of the box admits of its being dealt with in a modern flanging machine, and provided the width of bottom water space does not exceed $2\frac{1}{2}$ inches, then attachment by flanging is evidently the preferable method. If, however, the box is too large for the flanging machine, or if the flanging of the plate through any cause can only be effected by hand, attachment by means of a foundation ring will be more reliable than flanging, for whilst there are many workshops devoid of flanging machines, there are very few which are not furnished with a rivetting machine, and there should consequently be no difficulty in making sound work of the rivetting. When for any purpose an extra width of water space is required, a combination of the two methods may be adopted with advantage. To prevent undue length of rivets the foundation ring should not exceed $2\frac{1}{2}$ inches in width, and, for obvious reasons, a flange of greater width than $2\frac{1}{2}$ inches is equally undesirable.

The connection between the shell and firebox, at the fire-door seam, should never be effected wholly by the flanging outwards of the firebox plate to meet the shell, as all experience goes to show that this seam when so formed is not at all durable; the inner laps are very liable to fracture, and there is considerable difficulty in preventing leakage

or in making a satisfactory repair of such defects. The narrow wedge-shaped water space gets closed up by deposit which cannot easily be removed, and the inner laps, being thus remote from the water, are subjected to severe stress by the action of the fire, which, as already explained, causes, more or less rapidly, fracture and leakage at the seams. The insertion of a solid ring between the firebox and shell assists materially in preventing rapid deterioration of the fire-door seams, and such rings for boilers of average size may be made from 1½ inches to 2 inches in width, their depth being kept sufficient to allow for the required lap. To facilitate the escape of steam the width of the water space should increase from the bottom upwards, a fairly good rule being to reduce the diameter of the firebox by 1 inch to 1½ inches per foot of height. Fireboxes so constructed, although reduced to this extent in heating surface, give quite as good results in efficiency and duty as those which are built cylindrically, and experience has shown that they are more durable.

The following Tables of Proportions and Working-pressures for fireboxes are in accordance with the author's general practice, and, as the range of sizes given includes the majority of vertical boilers in use for general purposes, it has been thought that this method of presenting the subject would be more serviceable than any mere statement of rules. Special circumstances do arise from time to time which render some modification of the particulars in the tables necessary, but these, like all other exceptional matters in the working of boilers, can only be dealt with after careful investigation by engineers of experience. For working-pressures, in excess of those allowed by the table, the fireboxes require to be strengthened, and whilst this may be effected by increasing the plate thickness, such a course is not recommended except under special circumstances, and

in no case should the plates, even for the largest furnaces, be more than ½ inch in thickness. The additional strength required for higher working pressures may be obtained by having one or more rows of stud stays screwed through the plates of shell and firebox, the ends being rivetted over, and, notwithstanding the objections sometimes urged against the use of these stays, there does not appear to be any better means of obtaining the object aimed at.

When stud stays require to be fitted to fireboxes of the proportions given in the table, the rule is to make them ⅞-inch in diameter for the smallest firebox, and to increase their diameter by $\frac{1}{16}$th of an inch for each succeeding size of firebox, until the stays reach a diameter of 1¼ inches, a uniform pitch of about 7 inches being used for each boiler. The strength imparted by stays of the diameters and pitch here given is usually accounted as equal to that obtained by attaching a flanged encircling hoop to a furnace tube; as, for instance, if a firebox 5 feet high be fitted with one row of stays at the centre of its height, its length for the purpose of calculation is then taken as $L = \frac{5}{2} = 2{\cdot}5$ feet, which, it will be seen, just doubles the calculated working pressure. These stays, however, are subjected to deteriorating influences which do not affect the screws or rivets by which encircling hoops are secured to furnace tubes, and, as they are consequently more liable to become weakened, they should not be relied upon to the extent explained. Under ordinary conditions 75 per cent. of this result may be taken as a fair estimate, but in the event of the feed-water being of a corrosive nature, 50 per cent. may be sufficient, and it is important that stud stays should be frequently examined and tested, one or more being drilled out from time to time to ascertain their actual condition.

The formula by which the pressures in the table are calculated has been simplified as much as possible, and it is as follows:—$\frac{c\,t^2}{D\,L}$, where c is a constant which is varied according to the construction of the firebox, t the thickness of the plate in thirty-seconds of an inch, D the external diameter of the firebox in inches, and L the greatest distance in feet between supports. The variations of the constant are as follows:—

C = 80.—When the vertical seams are lap-jointed, the firebox being made as truly circular as is practicable by this method of construction.

C = 85.—When the vertical seams are welded, or butt-jointed, and fitted with covering straps.

C = 90.—When the vertical seams are lap-jointed, and the firebox is fitted with cross tubes as per table.

C = 95.—When the vertical seams are welded, or butt-jointed, and the firebox is fitted with cross tubes as per table.

It is understood that the fireboxes are to be made of mild steel, or a high quality of iron, and that when the vertical seams are lap-jointed, the deviation from true form will not exceed the thickness of the plate. Should the quality of the material and workmanship be of a questionable or doubtful nature, or should the firebox be defective in any respect, it will be necessary to reduce the constants more or less, but when the fireboxes are made of suitable material, and the construction is in accordance with good modern practice, the working pressures in the table are sufficiently within the ultimate strength to insure safety.

SHELLS.		FIREBOXES.				WORKING PRESSURES In Lbs. per Square Inch.			
						C = 80	C = 85	C = 90	C = 95
Length from Bottom Seam of Firebox to Crown of Shell.	Diameter.	Length from Bottom Seam to Crown of Firebox.	Mean Diameter (External).	Thickness in Thirty-Seconds of an Inch.	Number and Diameter of Cross Pipes.	Lap-Jointed without Cross Pipes.	Welded without Cross Pipes.	Lap-Jointed with Cross Pipes.	Welded with Cross Pipes.
6 ft. 9 in.	3 ft. 0 in.	3 ft. 3 in.	28 in.	$\frac{10}{32}$	Two 8 in.	88	93	99	104
7 „ 10 „	3 „ 6 „	3 „ 10 „	34 „	$\frac{11}{32}$	Two 8 „	74	79	84	88
9 „ 0 „	4 „ 0 „	4 „ 5 „	40 „	$\frac{12}{32}$	Two 9 „	65	69	73	77
10 „ 1 „	4 „ 6 „	5 „ 0 „	46 „	$\frac{13}{32}$	Three 9 „	59	63	66	70
11 „ 3 „	5 „ 0 „	5 „ 7 „	52 „	$\frac{14}{32}$	Three 9 „	54	58	61	64
12 „ 4 „	5 „ 6 „	6 „ 1 „	58 „	$\frac{15}{32}$	Four 10 „	51	54	57	61
13 „ 6 „	6 „ 0 „	6 „ 7 „	64 „	$\frac{16}{32}$	Four 10 „	49	52	55	58

Note.—In the event of stud stays being fitted, the greatest vertical distance between the rows of such stays, or between a row of stays, and the top or bottom seams of firebox will equal L in formula, but, as already explained, the result thus obtained should be reduced by at least 25 per cent. to insure a safe working pressure.

MOUNTINGS.—The mountings supplied with vertical boilers are not infrequently of very indifferent quality, and in other respects they are sometimes ill suited and badly arranged for their various purposes. Instances of undue "wear and tear," as well as serious accident, from such causes are well known to all who have given the matter any attention, and there is probably no economy less worthy of the name than that which is foolishly exercised in reducing the first cost of boilers by fitting them with the cheapest mountings in the market. The frequent changes that are made amongst the attendants of vertical boilers, together with the irregularities in working, to which they are more or less subjected, render the selection and arrangement of the mountings all the more important, and the following descriptive sketch of mountings may therefore be of service.

Branches.—Branches should be rivetted to the boilers for each of the following mountings, the flanges next the plates being accurately bedded and jointed to the curvature of the shell or crown plate as required. The somewhat common practice of bolting mountings direct to the plates is the cause of much trouble, and in the end proves a most costly proceeding. Cast-steel blocks are more easily manufactured and fitted to the crown plates than stand-pipe branches, but the latter when made of wrought iron or wrought steel are neater and preferable for mountings which are to be attached to the shell plates, and this course is usually recommended. The joint or outer flanges should be scraped up, so as to be steam-tight, with a thin coating of red lead, and due attention should be given to the diameter and pitch of the bolt-holes in the flanges, the latter being frequently too wide to prevent springing and leakage at joints quite perfect in all other respects.

Stop-Valves.—Many vertical boilers are not furnished

with independent stop-valves, but, except in those cases where the distance between the boiler and engine is very limited, and when the connections are of a permanent nature, there should invariably be a reliable stop-valve fitted direct to the branch on the crown plate, in addition to the stop-valve usually attached to the engine cylinder. The steam pipes between a vertical boiler and engine are more liable to injury from falling objects, &c., than those on fixed boilers; their erection is also, as a rule, of a more temporary character, with the result that breakages and leakages are by no means uncommon occurrences, and, to prevent undue delays, if not more serious trouble, from such causes, it is very important that the stop-valves should be of reliable manufacture, and jointed direct to boiler as explained. The dimensions of stop-valves will vary according to pressure and other circumstances, but for general use and ordinary pressures a boiler 3 feet in diameter may be fitted with a stop-valve $2\frac{1}{2}$ inches in diameter, and for each succeeding size of boiler up to 6 feet the diameter of the stop-valve should be increased by one quarter of an inch.

Safety-Valves.—A thoroughly reliable safety-valve is a necessity for all boilers, but, having regard to the irregularities which so often occur in the working of those of the vertical type, the greatest care is required to guard against accident arising from their safety-valves becoming defective. The objections advanced against the use of lever safety-valves, whether of the open or enclosed types, are specially applicable when they refer to vertical boilers, particularly such as are subject to frequent removal and changes of attendants. The safety-valve should be as compact as possible, so as to render its detachment unnecessary when the boiler is being removed from one place to another; it should also be designed so as to reduce or remove all chances of overloading, and its working parts should be as

few as practicable. These conditions may be said to exist in a properly designed valve of the directly loaded type, and it only requires the exercise of a little care in selecting from the catalogue of a good maker to secure the most suitable valve for the particular circumstances of each boiler. The ordinary dead weight valve may be used for boilers which are in stationary positions, but for boilers employed on steamboats, and cranes, &c., it is more satisfactory to use safety-valves which are loaded to the maximum working pressures by means of direct springs. Safety-valves are sometimes found attached to steam pipes or arranged as portions of the stop-valve castings, the apparent object being to avoid the necessity of making a separate outlet for the safety-valve; but, whilst it is desirable that the number of openings into the boiler should be no greater than what is actually required, it is absolutely necessary that the safety-valve should be what the name signifies, and the practice of attaching it to steam pipes or stop-valves may be viewed as little short of an attempt to entirely dispense with the use of this important fitting. When fixed on the steam pipe, the connection between the safety-valve and the boiler may be interrupted at any moment by the closing or even partial closing of the stop-valve, and when attached to, or made to form a portion of, the latter, its action is very uncertain; in short, all experience goes to show that the safety-valve should be quite independent of other mountings, and that it should be fixed direct to a branch on the crown plate of the boiler. It should also be tested by raising the steam to blowing-off pressure at least once per day, and it should be taken apart periodically for inspection and overhaul.

To find the proper areas of safety-valves see Table on page 21.

Feed-Valves.—The dangers attending the use of ordinary

stop-taps or valves, as a means of regulating the feed and preventing the water from being blown back, are too obvious to call for special reference, but it may be stated that the practice is not yet obsolete, notwithstanding the bitter experience that many have had.

Every boiler should be furnished with a feed-valve of the independent check or non-return type, having a screwed spindle for regulating the lift, and this fitting should be jointed direct to the rivetted branch on shell plate. There are evidently many opinions regarding the best position for the feed-valve on a vertical boiler, as they are found jointed at all parts under the water line. The question of convenience in the piping arrangements has, perhaps, a considerable influence in determining the exact point, and this doubtless accounts for so many boilers having the check-valves attached so as to deliver the feed at, or about, the bottom of the water space. The feed-pipes of Lancashire and Cornish boilers are almost invariably arranged so as to discharge about 3 inches above the furnace crowns, the object being to prevent draining or syphoning to a dangerous extent in the event of the check-valve being gagged or becoming defective, in which case the water, when at the level of the feed-pipes, would cease to be blown back, and thereby save the plates from injury by overheating. For the same reason the feed-pipes of multitubular and plain cylindrical boilers are usually kept a few inches above the tubes or plates exposed to the direct action of the fire, and apart from other advantages claimed for this method of introducing the feed-water, the one just explained is of sufficient importance to justify its adoption, there being many instances on record of collapses and overheating which would have been prevented had the feed-pipes been set in this manner. The precaution taken to guard against accident arising from defective check-valves is most applicable to the circumstances

of a large number of vertical boilers. The feed-water is often of a gritty nature, and the margin between the working level and furnace crown is small. The maintenance of the mountings is also a matter which receives but indifferent attention, and the feed-valves are consequently very liable to leakage through gagging or wear and tear of the bearing surfaces. The feed-water for vertical boilers is not, as a rule, heated to any useful degree before discharge, and when allowed to impinge against the firebox there is considerable danger of the plate being fractured by the sudden contraction of the part affected. For the reasons just explained, the centre of the feed inlet should be fixed at a point about 3 inches above the highest part of the firebox crown plate, and an internal T pipe should be attached so as to prevent the cold water from impinging on any part of the firebox or uptake-tube. The dimensions of the feed-valves for vertical boilers are usually too small, and the delivery branches are occasionally placed in such a position that the boiler pressure acts against the side of the valve instead of directly over it, the tendency being to keep the valve from closing properly after the pump or injector has ceased working.

Water Gauges.—One glass-tube gauge and two test-taps are the usual complement of water gauges on a vertical boiler. The test-taps, however, are very rarely used, and they soon become inoperative, which is pretty much the condition of the test-taps on all land boilers. It has, therefore, been found more satisfactory to dispense with them and to furnish each boiler with two glass-tube water gauges. There are several recognised makers of glass-tube gauges whose workmanship and material are thoroughly reliable, and as the taps of these gauges require to be frequently worked for testing purposes, none but those of good material and proper design can withstand the wear and tear, which

is often aggravated by the presence of grit and other foreign matter in the water. The taper of the taps, to insure easy working, should not be less than $\frac{1}{8}$th per inch of length, and allowances require to be made for regrinding the bearing surfaces as they become impaired. The practice of securing the taps in position by nuts and washers, at one time so common, has been discontinued by good makers. The screws at the ends of the taps were very liable to be broken or stripped when being tightened up, a process, it may be remarked, which was too frequently resorted to as a means of preventing leakage. The smaller ends of the barrels are now made solid, the open ends being furnished with stuffing boxes into which the glands are screwed so as to hold the taps securely in position, and in gauges of the best types the barrels are arranged for holding asbestos packing, which adds greatly to their durability. The steam and water thoroughfares should be made easily accessible, as they are always more or less liable to be choked, and they require to be regularly sponged out. Inattention to this precaution is almost certain to render the gauges unreliable, and it has led to the collapse of furnace crowns in many instances. The sponging out of the water passages is, as a rule, fairly well attended to, but the steam passages are often neglected, and there are boiler attendants who consider it quite unnecessary owing to the outlets being well removed from substances such as would cause obstruction. This, however, is an erroneous conclusion, and particularly so with reference to the gauges on vertical boilers. When priming occurs the scum on the surface of the water and the fine solid matter held in suspension are carried up into the steam space, and the passages of glass gauges, steam gauges, and other fittings are often choked up, or partially so, by this means. The steam disengaging surfaces of vertical boilers, being of limited area, render them very liable to priming

when the feed-water is dirty, or when the fires are forced, both of which conditions are often met with, and the precautions just explained are consequently all the more necessary. In the event of the steam passages becoming choked, or even partially closed, the pressure above the water in the glass tube would be reduced, which would cause the indicated water level to rise proportionately higher than the actual level in the boiler, and the gauge would indicate a sufficiency of water, even after the level in the boiler had become so low as to cause overheating and collapse of the furnace plates. An obstruction in the water passages would produce somewhat similar results, for although water may be prevented from entering the glass tube through the usual channel, the tube would still be filled with water by the condensation of steam from the upper end, and attendants have thereby been deceived as to the actual level of the water in their boilers. When new glass tubes are being inserted care should be taken to ascertain that they do not overlap the passages, and, as proper means for cutting glass tubes to correct lengths are not always at hand, it is important that a few spare glasses with the necessary packing should be kept in stock. To prevent the shell plates from being corroded by the blowing through of the gauges, suitable drain pipes should be attached to the bottom taps, and the gauges should be set and tested from time to time, as explained on pp. 5 and 6.

Blow-off Cocks.—The judicious use of the blow-off tap, so beneficial to most boilers, is a practice which is seldom carried out in the working of vertical boilers, and this is chiefly due to the unsuitability of the taps supplied; they are usually too small to be of much service in carrying away the solid matter deposited from the feed-water, and they are frequently found in a leaky condition and inoperative. The conditions attending the working of ver-

tical boilers are doubtless very trying at times, but they simply point to the greater necessity for having the blow-off taps made of good design and material, if such mountings are to be of any use whatever. The "gland tap" blow-off cock, when made throughout of gun-metal and properly proportioned, acts fairly well, but, like the water gauge, it has been greatly improved of late years through having the barrel arranged for the insertion of asbestos packing, by which it is much better adapted for withstanding the somewhat severe tests incidental to the working of vertical boilers. As a precaution against accident, the blow-off cock should be arranged so that the spanner for turning the plug cannot be applied or removed except when the plug is closed. The most recent departure in the design of the blow-off apparatus is that known as the "Parallel Slide-Valve Blow-off," and, judging by the results so far obtained from its working, it appears to justify the confidence of those who have adopted it. This "blow-off" requires no packing, and its construction effectually removes any tendency to become fast or stiff in working, such as frequently proves so troublesome in the use of the ordinary blow-off cock. The valve is actuated by a rack and pinion which admits of easy manipulation, and generally this arrangement seems to be well adapted for overcoming the difficulties so commonly experienced by the use of ordinary blow-off cocks on vertical boilers.

Steam Gauges.—Of all the mountings attached to the ordinary vertical boiler, there are none more difficult to keep in order than steam gauges. The variations of pressure (sometimes sudden), the exposure to all kinds of weather, and the exigencies common to many boilers of this type, affect the pressure gauges materially, and frequently render them useless. It is, therefore, of special importance that only gauges of the best construction should be used,

and that they should receive the most careful attention. The "Bourdon" gauge, previous to the expiry of the patent, was one of the most reliable and durable of steam pressure indicators, but now that the patent is lapsed, there are hundreds of the so-called Bourdon gauges which are worse than useless, and in specifying it is necessary to add the words, "Bourdon's own make," or to select a manufacturer, whose reputation will be a guarantee for the supply of a really good article. The gauges manufactured by Schaeffer & Budenberg have also attained to a high degree of efficiency, many of the recent improvements made by this firm being admirably adapted for the requirements of the increased pressures now becoming general. The pipe connecting the steam gauge to the boiler requires to be arranged so as to insure the presence of a body of water between the gauge and the steam space; the water fills the spring, or space under the diaphragm, and becomes the medium for transmitting the pressure. By such means the spring, or diaphragm, is kept at a low and fairly uniform temperature, both of which conditions have an important effect on the durability of the gauge. The connection to the boiler should be fitted with stop-taps, suitably placed, so as to allow of the gauge being detached for testing or repairs whilst the boiler is under steam, and also for blowing out or clearing the pipes without requiring to remove the gauge. The ordinary methods of connecting steam gauges by bent tubes are effective so long as the tubes are in order, but as these are difficult to clean, and cannot be emptied without removing the gauge, the pipes are very liable to be neglected and destroyed during frosty weather. The steam-gauge pipe should be connected direct to the boiler, the dial being in as prominent a position as possible, and all available means should be adopted for its protection. The practice of fixing gauges on the steam pipes is danger-

ous, inasmuch as they may be cut off from the boiler by the closing of the stop-valve, and in any case the flow of steam in the piping prevents them indicating the actual pressure in the boiler. The steam gauge should be checked by the blowing-off pressure of the safety-valve, and when they do not agree the former should be tested. All gauges should be graduated to double the intended working pressure, and the maximum load allowed on the safety-valve should be clearly indicated by a red line on the dial.

Fusible Plugs.—As a stand-by in the event of low water a good fusible plug is of the greatest service, and, although instances may be cited wherein it failed at the all-important moment, such failures are generally due to the absence of ordinary care in the cleaning or changing of the alloy. The position of the fusible plug necessarily keeps it out of view, and as its reliability cannot be determined, except during a grave emergency or by a special test, it is very often forgotten during the working of the boiler, and neglected when the boiler is off. The melting point of the fusible metal is raised considerably by the prolonged action of the heat, and even in plugs of the best design it has been found necessary to renew the alloy at least once a year. When the metal is in direct contact with the water, particularly if of a corrosive nature, this hardening tendency seems to be greater, and as the metal is otherwise deteriorated by corrosive action, plugs so designed require to be more frequently changed. The importance of keeping the fusible metal from direct contact with the fire and water is now very generally recognised. It is also important that the plug should be constructed so as to allow of the metal being replaced without difficulty, as the absence of this feature is a common cause of complaint, and accounts for much of the apparent neglect on the part of boiler attendants. The "Lancashire Fusible Plug," whilst possessing all the advantages of other

good plugs is also designed to meet the requirements just explained, and special sizes of this plug are manufactured for vertical boilers. To obviate delay in the event of a plug being melted out, as well as to provide for the annual renewals under ordinary circumstances, a number of fusible cones should always be kept in stock, and those responsible for the boilers should be warned of the necessity for cleaning the plugs and renewing the fusible metal as required.

MANAGEMENT OF VERTICAL BOILERS.

The situation of a vertical boiler should always be such as will allow of easy access to every part of the external shell, and to guard against the bottom seam or ash-pit plates being corroded by contact with ashes or moisture, it is desirable that the boiler should be set on iron pedestals, which would also facilitate the cleaning and inspection of the interior of the firebox. When the boiler is thoroughly protected from exposure to the weather it should be covered with a good non-conductive composition, but if placed outside or only partially protected it is better to scrape and paint the shell plates from time to time as required.

The **duties** of boiler attendants may be briefly summarised as follows:—

(1) Ascertain by careful examination that the boiler, mountings, and feed pump are in reliable working order.

(2) Before kindling the fires check the indicated water level by proper trial of the gauges (see pages 5 and 6).

(3) Be certain that the blow-off apparatus is properly shut off.

(4) Allow at least one hour for the raising of steam in small boilers, and one and a-half hours for those of the larger sizes. Forced or rapid firing is a dangerous practice

in every case, but particularly so with vertical boilers when raising steam from cold water.

(5) Do not open the fire door oftener than necessary, and keep it open for as short a time as practicable.

(6) Try the safety-valve as the pressure rises, and when at its maximum check with steam gauge.

(7) Maintain as nearly as possible a uniform water-level, and ascertain by the temperature of the feed pipe or connection that the back pressure valve is tight.

(8) Check the working of the mountings regularly, particularly the safety-valves and water gauges. If the water flows into the glass tubes sluggishly clean out the passages. Keep the boiler and mountings tidy, and do not allow ashes or refuse to lie on the footplates.

(9) If the glass gauges or engine cylinder show priming, check the fire and outflow of steam, blow off a little, and pump in fresh water; if priming continues have the boiler and feed tank cleaned out.

(10) Report all defects to the manager or inspecting engineer, and keep a careful note of such reports, as they may be valuable in the event of explosion or accident occurring.

CLEANING.

(1) Draw the fire or allow it to burn out, and do not blow off until the boiler is cool.

(2) Always ease the safety-valve before slackening the man-hole joints.

(3) Open all hand- and mud-holes, and remove any scale or loose deposit at water side of plates and tubes. Brush the soot from fire side of plates and cross tubes.

(4) Examine all mountings, clean out watergauge passages, and scrape or renew the cap of fusible plug as required.

(5) Have all leakages attended to and examine plates and uptake-tube for corrosion, grooving, or other defects.

(6) Before filling with water be certain that no tools or blocks, &c., are left in the boiler.

(7) If the boiler is to be laid aside for a time, remove man-hole and mud-hole covers, and keep the boiler in a dry situation. Wash out and examine plates and mountings before refilling for work.

(8) In frosty weather take precautions to prevent freezing of the water in the boiler during the night. Shut the water gauge taps; empty the glass tubes and drain the steam gauge connections. Examine also the feed pipes and pump or injector connections before starting.

The heating of the feed-water for vertical boilers adds greatly to their durability, and when there is no properly arranged feed-heating system, injectors should be used in preference to pumps. On no account should the feed-water be heated by contact with the exhaust steam, as by this method the cylinder lubricants obtain access to the boiler and are certain to cause much undue wear and tear, besides endangering the safety of the boiler through over-heating of the furnace plates. The gain in economy to be derived by heating the feed-water in this manner is usually very small, whereas, with a separate feed-heater a marked decrease of the coal consumpt may be effected.

BURSTING PRESSURES PER SQUARE INCH.

Tensile strength taken at 62,000 lbs.; Joints taken at 56 and 70 per cent. of solid plate for single and double rivetting.

Diameter of Shell in Inches.	SINGLE RIVETTING.							DOUBLE RIVETTING.							Diameter of Shell in Inches.
	$\frac{1}{4}''$	$\frac{5}{16}''$	$\frac{3}{8}''$	$\frac{7}{16}''$	$\frac{1}{2}''$	$\frac{9}{16}''$	$\frac{5}{8}''$	$\frac{1}{4}''$	$\frac{5}{16}''$	$\frac{3}{8}''$	$\frac{7}{16}''$	$\frac{1}{2}''$	$\frac{9}{16}''$	$\frac{5}{8}''$	
30	579	723	868	1013	1157	1302	1447	723	904	1085	1266	1467	1628	1808	30
33	526	657	789	921	1052	1184	1315	657	822	986	1151	1315	1479	1644	33
36	482	603	723	844	964	1085	1205	603	753	904	1055	1205	1356	1507	36
39	445	556	668	779	890	1002	1113	556	696	835	974	1113	1252	1391	39
42	413	517	620	723	827	930	1033	517	646	775	904	1033	1162	1292	42
45	386	482	579	675	771	868	964	482	603	723	844	964	1085	1206	45
48	362	452	543	633	723	814	904	452	565	678	791	904	1017	1130	48
51	340	425	511	596	681	766	851	425	531	638	745	851	957	1063	51
54	321	402	482	563	643	723	804	402	502	603	703	804	904	1005	54
57	304	381	457	533	609	685	761	381	476	571	666	761	857	952	57
60	289	362	434	506	579	651	723	362	452	543	633	723	814	904	60
63	275	344	413	482	551	620	689	344	431	517	603	689	775	861	63
66	263	329	394	460	526	592	657	329	411	493	575	657	739	822	66
69	252	314	377	440	504	566	629	314	393	472	550	629	708	786	69
72	241	301	362	422	482	543	603	301	377	452	527	603	678	753	72
75	231	289	347	405	463	521	579	289	362	434	506	579	651	723	75
78	222	278	334	389	445	501	556	278	348	417	487	556	626	696	78
81	214	268	321	375	429	482	536	268	335	402	469	536	603	670	81
84	207	258	310	362	413	465	517	258	323	387	452	517	581	646	84
87	200	249	299	349	399	449	499	249	312	374	436	499	561	623	87
90	193	241	289	338	386	434	482	241	301	362	422	482	542	603	90
93	187	233	280	327	373	420	467	233	292	350	408	467	525	583	93
96	181	226	271	316	362	407	452	226	283	339	396	452	509	565	96
99	175	219	263	307	351	394	438	219	274	329	384	438	493	548	99
102	170	213	255	298	340	383	425	213	266	319	372	425	479	532	102
105	165	207	248	289	330	372	413	207	258	310	362	413	465	517	105
108	161	201	241	281	321	362	402	201	251	301	352	402	452	502	108

STEEL BOILERS.

STRENGTH OF RIVETTED JOINTS.

TENSILE STRENGTH TAKEN AT 28 TONS PER SQ. IN. SHEARING STRENGTH TAKEN AT 23 TONS PER SQ. IN.

Thickness of Plate.	Diameter of Rivet holes.	Single Rivetted Laps.			Double Rivetted Lap.			Double Butt Straps. Double Rivetted.			Treble Rivetted Lap.		
		Pitch of Rivet holes.	Percentage of Joint to Solid Plate.		Pitch of Rivet holes.	Percentage of Joint to Solid Plate.		Pitch of Rivet holes.	Percentage of Joint to Solid Plate.		Pitch of Rivet holes.	Percentage of Joint to Solid Plate.	
			Plate Section.	Rivet Section.		Plate Section.	Rivet Section.		Plate Section.	Rivet Section.		Plate Section.	Rivet Section.
Inch.	Inch.	Inches.	Per Cent.	Per Cent.	Inches.	Per Cent.	Per Cent.	Inches.	Per Cent.	Per Cent.	Inches.	Per Cent.	Per Cent.
$\frac{3}{8}$	$\frac{3}{4}$	$1\frac{7}{8}$	60	51	$2\frac{1}{2}$	70	77	3	75	112	...	...	...
$\frac{7}{16}$	$\frac{13}{16}$	$1\frac{7}{8}$	56	52	$2\frac{3}{4}$	70	70	$3\frac{1}{8}$	74	109	3	72	97
$\frac{1}{2}$	$\frac{7}{8}$	2	56	49	$2\frac{7}{8}$	69	69	$3\frac{1}{4}$	73	106	$3\frac{1}{4}$	73	91
$\frac{9}{16}$	$\frac{7}{8}$	...	...	...	$2\frac{5}{8}$	66	66	$3\frac{3}{4}$	76	82	$3\frac{1}{2}$	75	75
$\frac{5}{8}$	$\frac{7}{8}$	...	...	...	$2\frac{1}{2}$	65	63	$3\frac{5}{8}$	76	76	$3\frac{1}{4}$	73	73

SPECIFICATION OF A LANCASHIRE BOILER FOR A WORKING PRESSURE OF 200 LBS. PER SQUARE INCH.

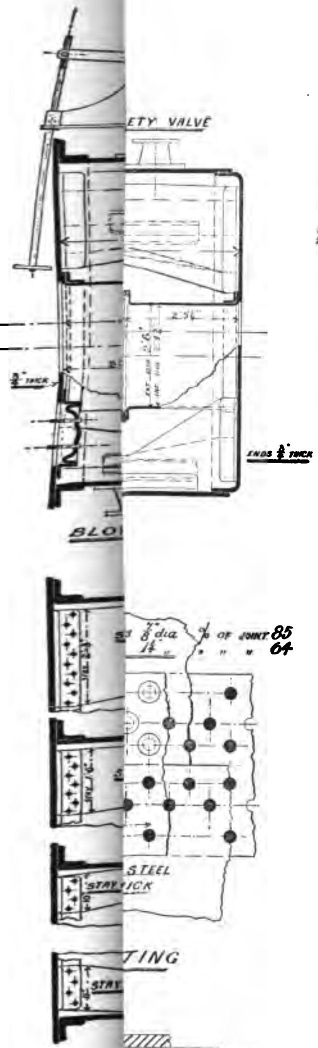
Dimensions and Particulars.

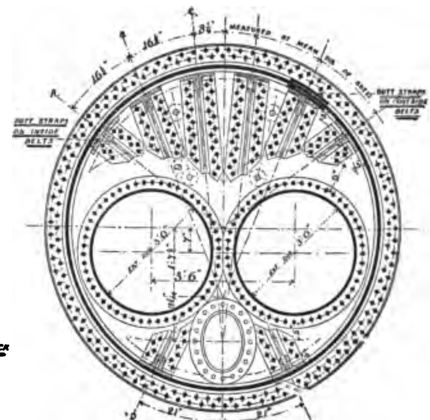
Length of boiler,	30 ft. 0 in.
Diameter of shell,	7 ft. 6 in.
Diameter of furnace tubes—	
First eleven rings to be	2 ft. $10\frac{3}{4}$ in.
Twelfth ring to be tapered to	2 ft. $4\frac{3}{4}$ in.
Thirteenth ring to be parallel,	2 ft. $4\frac{3}{4}$ in.
Diameter of rivet holes—	
Shell, butt joints,	$\frac{7}{8}$ in.
,, circular joints,	$1\frac{1}{4}$ in.
Furnace tubes,	$\frac{7}{8}$ in.
Gusset stays,	$\frac{7}{8}$ in.
Diameter of bolts, gusset-stay plates,	$1\frac{1}{8}$ in.
Thickness of plates—	
Shell,	$\frac{7}{8}$ in.
Furnace tubes,	$\frac{5}{8}$ in.
,, caulking rings,	$\frac{1}{2}$ in.
Ends,	$\frac{3}{4}$ in.
Butt straps,	$\frac{13}{16}$ in.
Gusset-stay plates,	$\frac{7}{8}$ in.
Shell angle rings,	6 in. × 6 in. × $\frac{7}{8}$ in.
Gusset angle bars,	5 in. × $5\frac{1}{2}$ in. × $\frac{3}{4}$ in.
Weight of plates—	
Shell,	35·7 lbs. per sq. ft.
Furnace tubes,	25·5 ,, ,,
Ends,	30·6 ,, ,,
Butt straps,	33·1 ,, ,,
Gusset plates,	35·7 ,, ,,

Note.—The diameter of the shells and furnace tubes to be measured internally, that of the shell being measured inside the outer rings of plates.

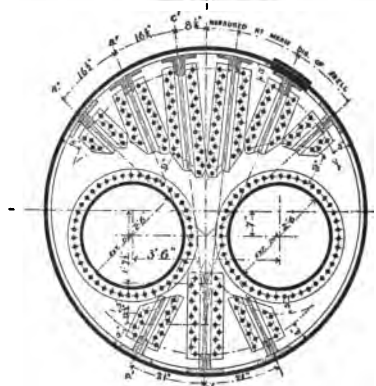
Materials.—The shell plates, butt straps, and end plates to be made of Siemens-Martin steel, having a tenacity not exceeding 32 tons per square inch, or less than 28 tons, and to afford an elongation of at least 20 per cent. in a test piece 10 in. long.

Angle Rings and Furnace Tubes to be made of Siemens-Martin





FRONT END



BACK END

steel, having a tenacity not exceeding 28 tons, nor less than 24 tons per square inch, and to have an elongation of at least 25 per cent. in a length of 10 inches.

Brands.—Each plate to be branded and numbered, care being taken during construction that the numbers and brands will be in a prominent position. The tensile strength and ductility of each plate to be stated on the record of tests furnished by the manufacturer.

Test Strips.—Strips from the plates of shell, furnace tubes, and angle bars are to be capable of being bent cold to a radius of one and a-half times the thickness of the plate, without fracture, after having been heated to a cherry red and plunged into water of 80° F. The welding properties of strips taken from the angle bars and furnace plates are also to be ascertained by actual trial, and generally the materials are to be capable of withstanding the various tests to the satisfaction of the Inspector appointed for the purpose.

Rivets.—To be of specially selected rivet steel, the tensile strength of which shall be from 26 to 30 tons per square inch, and the elongation in a length of 10 inches to be not less than 25 per cent. Samples of the rivet steel are to be submitted to bending, breaking, and flattening tests.

Construction.—The shell to consist of nine parallel belts of plating of equal width, alternately in and out, the first belt of plates being an outer one. Each belt to be formed of one plate, and all to be made perfectly cylindrical.

Seams of Rivets.—The longitudinal seams of shell to be butt jointed, with cover straps inside and outside, and to have three rows of rivets at each side of the butts, or six rows in all, the outer rows being spaced at twice the pitch of the inner rows. These seams to be at the upper side of boiler, right and left sides alternately, and to be arranged so as to clear the brickwork and mountings. The circular seams to be double rivetted with lap joints.

Butt Straps.—The ends of the butt straps, where they tuck under the ring seams, may be thinned by planing or by forging. If the strips are heated for forging or bending they should be afterwards annealed.

End Plates.—Each end plate to be rolled in one piece. The front end to be attached to shell by a solid welded angle steel ring, which shall be fixed externally, the back end plate being flanged to meet the shell. The edges of both plates and angle rings to be neatly turned up, and the holes for flues to be cut out by machine.

Stays.—The steam space portion of end plates to be strengthened by means of six gusset-plate stays, the total section of which must not be less than 70 square inches when measured at their weakest parts. The bottom rivets in all the gusset-stay angles on the end plates must be concentric with the rivets joining the furnace tubes to the end plates, and the distance

10

between the bottom rivets of stays and the rivets joining the internal flues to be 9 inches. Each end plate to be strengthened below the furnace tubes by means of two gusset-plate stays at front end and three at back end, all the gussets being united to shell and ends by double angle bars. The gusset plates to be secured to shell and end plate angles by turned bolts of the diameter specified, the holes for these bolts being broached out when the plates and angles are in position.

Furnace Tubes.—The furnace tubes to be truly cylindrical, the longitudinal joints being welded. Each tube to consist of not less than 13 belts of plating united to each other by Adamson's flanged seams, having solid caulking rings between each. The flanges for the attachment of the tubes to each end plate are also to be strengthened by means of steel collars of same thickness as tubes, which are to be shrunk on and flanged with the tube plates, and rivetted to them by rivets pitched about 6 inches apart, or as an alternative the furnace tubes may be attached to end plates by solid flanged collars. Care must be taken to prevent the circular seams of furnace tubes from falling in line with each other or with those of the shell. Each furnace tube to be fitted with four of Galloway's steel cross pipes, the first of which shall be placed vertically in the fifth belt of plates, the others being fitted in the seventh, ninth, and eleventh belts of plates, and set towards right and left sides alternately at an angle of 30 degrees from the vertical. Each furnace tube to taper at the last belt but one from the back end, the last belt in each being made parallel to the diameters specified. Each furnace tube to be tested by hydraulic pressure to 100 lbs. per square inch before being placed in position.

Rivet-Holes.—All rivet-holes to be drilled full size through the solid plates, and wherever practicable, the plates, angles, and flanges are to be drilled in position. The holes are afterwards to be slightly counter sunk at the rivet heads, and care must be taken to remove the burr from between the plates. Should any of the holes be unfair when the plates are drawn up, they must be carefully broached out before rivetting, and any hole which cannot be drilled in position must also be broached out after the parts have been put together, the drilled diameter of the holes being kept slightly under full size to allow of this being done.

Rivetting.—To be done wherever practicable by machine.

Edges of Plates.—The edges of all the plates and butt straps throughout the shell to be planed, the front and back end plates to be turned at the furnace tube openings, and the outer edges of the seams of the furnace tubes to be faced in machine. The distance between the centre of rivet holes and edges of plates to be equal to one and a-half times the diameter of the rivets.

Caulking.—The seams throughout to be caulked or fullered internally and externally.

Sketches.—The details of construction are throughout to be in accordance with the accompanying drawings.

Flanging and Welding.—These to be done with the special tools and appliances for such purposes, and all plates which have been worked in the fire are afterwards to be annealed when completed.

Inspections during Construction.—The makers, in addition to advising purchasers when the plates are to be tested at the Steel Works, will also be required to send notice at the following stages of construction :—

1st. When the plates are being drilled, and before rivetting is begun.

2nd. When they are in process of being rivetted.

3d. When the shell is completed, and before the flues are put into position.

4th. When the flues are prepared for testing previous to being placed in shell.

5th. When the boiler is completed and ready for being tested.

In addition to these special inspections, the boiler must be open to examination by the purchaser's inspector at all reasonable times during construction.

Tests.—The boiler to be tested to 300 lbs. per square inch by water pressure in the maker's yard, and to sustain the same to the satisfaction of the Inspector appointed for the purpose. The boiler must also be tested when it has been placed on its seating at the purchaser's works, with all the mountings in position except the safety-valves, it being understood that these valves will be tested and guaranteed by the makers. The date of make and pressure to which the boiler is tested, and the initials of the Inspector to be legibly stamped on the front end plate.

MOUNTINGS AND FITTINGS.

Steam Stop-Valve.—One steam stop-valve, 6 inches diameter, having malleable-iron crosshead and wrought-iron pillars, by approved maker, the name of maker being stated in tender.

Safety-Valves.—One direct spring loaded safety-valve, 2½ inches diameter, and one combined high-pressure and low-water valve, 2½ inches diameter, both of which are to be set for a maximum pressure of 200 lbs. per square inch. The names of makers and the number of these valves on makers' catalogue to be stated in tender.

Feed-Valve.—One combined feed-regulating and back-pressure valve, 2 inches diameter, to be attached on top of first ring of shell plates, and to be fitted with an internal pipe arranged to discharge horizontally about 3 inches above the level of the furnace crowns. Suitable hand wheel and gear to be provided for operating feed-valve from foot plate.

Water Gauges.—Two sets of asbestos packed water gauges of an approved automatic type, having the tubes protected by shields of wire gauze or strong plate glass. Each gauge to be united to rivetted branches by flanges, and to be provided with a solid drawn copper drain pipe of suitable length. The water level to be 5 inches above the furnace crowns when it is visible at bottom of glass tubes.

Water-Level Pointer.—One brass water-level pointer of neat design to be fixed at a height of about 10 inches above the furnace crowns.

Steam Gauges.—Two 7-inch steam-pressure gauges of Bourdon's or Schaeffer & Budenberg's special make for high pressures, graduated to 300 lbs. per square inch, and fitted with syphon and testing taps complete.

Testing Tap.—A steam tap with union for Richard's indicator to be attached in convenient position for testing the pressure gauges.

Blow-off Tap and Bend.—One 2½ inch asbestos-packed blow-off tap, or one Patent Equal-Expansion Shell Tap, entirely of gun-metal, and constructed so as to prevent the key being removed until the tap has been closed.

One cast-steel elbow-pipe of approved form, having an internal diameter of 6 inches at its upper end, and tapering down for connection to tap. The bend pipe to be strongly ribbed, and the metal to be not less than 1¼ inches in thickness at the largest diameter.

Anti-Priming Pipe.—One perforated cast-iron pipe to be placed horizontally in steam space and connected to steam stop-valve. The pipe to be carried close to the crown of shell by means of suspenders attached to a small rivetted bracket at each end. The united area of the perforations in this pipe to be about 25 per cent. in excess of the area of the stop-valve, and suitable provision to be made for draining the pipe.

Fusible Plugs.—One Lancashire fusible plug to be fitted into the crown plate of each furnace directly above the centre of the fire grate. Spare caps to be supplied.

Man-holes.—One of M'Neil's flanged compensating rings, with patent embossed door, to be fitted on top of shell, and one at front end below furnaces. The rings and doors to be of the makers proportions for the working pressure. The opening into shell to have the major axis placed circumferentially, and to be further compensated for by a steel plate fixed externally. The opening below furnaces to have the major axis placed vertically, all being as shown on the accompanying drawing.

Branches for Mountings.—Branches of wrought steel for the various mountings to be attached by double rivetting at the positions shown on drawings.

Furnace Mouth-piece.—One wrought-iron or steel mouth-piece for each furnace, finished off with neat moulding outside, and fitted internally with a cast-iron arch-piece surrounding the fire-door for carrying a fire-clay

lining to protect the furnace front. The cast-iron door to be fitted with a sliding ventilator, affording an area of about 50 square inches, as well as with an internal perforated baffle plate.

Dead Plates and Fire-Grates.—Two dead plates and a complete set of fire-bars in two lengths of 3 feet each, the total length of grate surface being 6 feet. The dead plates as well as the mid-bearers for fire-grate to be carried by wrought-iron brackets rivetted to the sides of furnaces.

Flue Doors.—Two side flue doors and frames sufficiently large to afford easy access to external side flues.

Damper and Frame.—One damper plate and frame, with all fittings and connections necessary to allow of adjusting the dampers from foot plate.

Floor Plates and Frame.—A complete set of floor plates with frames and fender flange. These plates to extend across the entire front of the stokehole, and to be of convenient width for handling.

Delivery of Boiler.—The boiler to be delivered on its seat at the Purchaser's works. All the mountings and fittings herein specified being connected by the contractor, and to be free from injury or defect of any kind. The contractor to be responsible for placing the boiler on its seating, and he will require to furnish skilled labour and all special tackle that may be necessary for this purpose, labourers' assistants being provided by the Purchaser.

Generally.—The material and workmanship to be of the highest quality, and the boiler to be constructed throughout to the satisfaction of the Inspector appointed by the Purchaser.

Form of Offer.

MESSRS. ....

GENTLEMEN,

........................hereby make offer to build and place upon its seating at your works...

ONE LANCASHIRE BOILER, the material, workmanship, and conditions of contract being in strict accordance with the accompanying specification, and drawings. It is also understood that wherein the accompanying specification does not describe minutely every detail necessary for the satisfactory completion of the boiler, that these will be attended to by ...., and the boiler will be left on its seating complete, and ready for work, to the satisfaction of your Inspector, for the sum of £...say..

...................propose to supply the mountings as follows :—

Steam Stop-Valve, as made by...

Number.........................on catalogue.

Safety-Valves, as made by...

Numbers........................on catalogue.

Feed-Check Valve, as made by...

Number.........................on catalogue.

Water Gauges, as made by..

Number.........................on catalogue.

Blow-off Tap, as made by..

Number.........................on catalogue.

Steam Pressure Gauges, as made by...

...................also guarantee delivery of the boiler complete and ready for work within.................................weeks from date of acceptance.

..................would make the boiler of Siemens-Martin steel, as manufactured by...

If the furnace fronts, doors, fire bars and bearers specified should not be required, a reduction of £............................would be made in price of boiler.

....

GENTLEMEN,

Yours faithfully,

....

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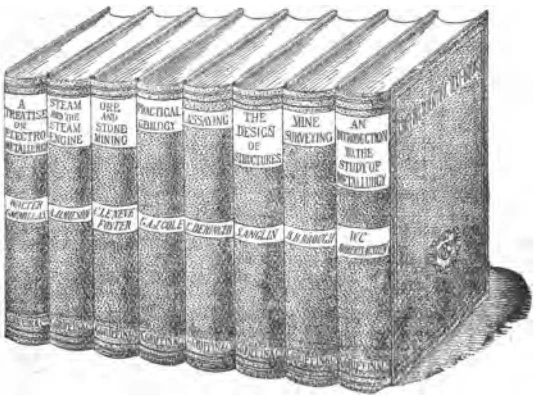

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